

Factors Influencing Yield, Color, Size and Growth in Apples

A T H E S I S

Presented to the Faculty of the Graduate School
of Cornell University for the Degree of

DOCTOR OF PHILOSOPHY

BY

JOHN POGUE STEWART





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BY JOHN P. STEWART.

INTRODUCTION

The following paper is essentially a record of experiments and observations bearing upon the subject above, in which especial emphasis has been laid upon principles and the present apparent reasons for the particular results secured. It is based chiefly upon work started by the writer in Pennsylvania in the spring of 1907 and maintained continuously ever since. Relevant observations and experiments elsewhere, however, have also been introduced wherever they seemed to throw light upon the particular problems involved.

Since principles and causes have been uppermost in our present treatment, more than usual attention has been given to preparing the way for the discussion and interpretation of results. On this account, approximately the first third of the paper is devoted to what may be called preparatory matter, some of which may seem to have only remote connection with the particular questions at hand. In most cases the connection appears, however, in the subsequent discussion, and it all remains as a fund of description and general facts to which we may refer later, and upon which we may be able to draw in the explanation of new and possibly unexpected phenomena.

General Status of the Apple Industry.

Among the fruits of America, the apple is by far the most largely grown. According to recent reports of the census, with reference to yield and number of trees, the apple far surpasses all other tree fruits combined. The exact extent of this excess may be seen in the following tables, I and II.

Table I.—Production of Fruits in the United States in 1889, 1899 and 1909; and Number of Trees of Bearing Age in 1890, 1900 and 1910.

(As reported in the Eleventh (1890), Twelfth (1900) and Thirteenth (1910) Census).

Kind of Fruit. ¹	1890.	1889.	1900.	1899.	1910.	1909.
	Trees of bearing age.	Production (bushels.)	Trees of bearing age.	Production (bushels.)	Trees of bearing age. ²	Production (bushels.)
Apples, -----	120,152,795	143,105,689	201,794,764	175,397,626	151,322,840	147,522,318
Pears, -----	5,115,065	3,064,375	17,716,184	6,625,417	15,171,524	8,840,733
Apricots, -----	1,582,191	1,001,482	5,010,139	2,642,128	3,669,714	4,150,263
Cherries, -----	5,638,759	1,476,719	11,943,287	2,873,499	11,822,044	4,126,099
Peaches and nectarines.	12,001,129	3,561,042	82,200,414	8,807,186	94,506,657	35,470,276
Plums and prunes.	7,078,191	2,554,392	30,780,892	8,764,032	23,445,009	15,480,170
Totals without apples.	32,015,325	11,658,010	147,650,916	29,712,262	148,614,948	68,067,543
Ratio of apples to other fruits.	3.753	12.275	1.366	5.903	1.018	2.167

¹Table I. is from Table 3, part VI, pp. 700-701, of the 12th Census Report, and from advance bulletins of the 13th Census. The totals and ratios have been added by us.

²In 1910 there were also reported 65,792,000 apple trees not of bearing age. No account was taken of such trees in the earlier censuses.

Table II.—The Value of Specified Kinds of Fruits Produced in the United States in 1899 and in 1909.

(As reported in the Twelfth and Thirteenth Census.) (From Table 36.)

	Total.	Orchard Products. ¹	Grapes. ²	Small Fruits.	Sub-tropical Fruits. ³
1899, -----	\$131,098,790	\$83,750,961	\$14,090,234	\$25,029,757	\$8,227,838
1909, -----	217,575,542	140,867,347	22,026,961	29,974,481	24,706,753

¹ Including value of cider, vinegar, &c., in 1899, but not in 1909.

² Including value of raisins, wine, &c., in 1899, but not in 1909. The number of vines and production of grapes was as follows:

1899, No. of vines, 182,227,655; fruit, 1,300,751,066 lbs.; wine, 31,671,111 gal.

1909, No. of vines, 224,097,719; fruit, 2,570,936,310 lbs.; value, \$22,025,060.

³ Includes bananas, citrons, figs, guava, kaki, lemons, olives, oranges, limes, pineapples, pomelos, and unclassified subtropical fruits.

This relative position of the apple is doubtless to be attributed to its greater certainty of a crop, the many uses and long season of the fruit, and its wholesome effect upon health in general.

In spite of the present magnitude of the industry, however, the present movement into it is apparently more rapid than ever before.

Orchards of thousands of acres, under expert direction, are being projected and established. Leading fruit regions report more trees recently planted than are now in bearing. The demand for apple trees is so great that the wholesale price has practically doubled in the last two years, and in spite of this some of our largest nurseries are sold out completely by February or earlier. In short, a regular apple boom seems to be in possession of the favored regions throughout the country; and, with the increasing demands for all food products, with the high returns available under proper conditions, and with the opportunity afforded for an open-air life, no general check in the growth of the industry is now in sight.

In view of all this, it has been suggested that the danger of overproduction is impending. But judging from past experience, this danger is probably relatively slight, with the possible exceptions of occasional years and of fruit in the lower grades. In fact, the failure of production to keep pace with the demands and with the increase in planting is one of the marked features at the present time. Thus in Table I, between 1890 and 1900, it will be noted that the increase in number of bearing apple trees is 67.3 per cent., while the increase in yield is only 22.5 per cent. During that period, therefore, the increase in trees was about three times as rapid as that in yield.

This same general fact is brought out more forcibly in the estimates of one of our leading agricultural papers. Its estimates of the apple crops for the past eleven years are shown in Table III. As compared with the census figures, these estimates are noticeably lower, and their accuracy is of course unknown to the writer. They are said to be prepared with considerable care, however, upon the estimates of many observers in the various regions covered, and they are at least interesting in their exhibit of the trend of production for the years indicated.

Table III.—APPLE CROPS OF THE UNITED STATES, IN 1899, AS PER UNITED STATES CENSUS, AND IN 1899 TO 1910, AS ESTIMATED BY THE AMERICAN AGRICULTURIST.

State.	Estimate of American Agriculturist.						
	Census Estimate.	1899.	1900.	1901.	1902.	1903.	1904.
	Barrels.	Barrels.	Barrels.	Barrels.	Barrels.	Barrels.	Barrels.
Maine.	474,000	820,000	950,000	570,000	1,200,000	1,050,000	1,425,000
New Hampshire,	659,000	1,100,000	1,200,000	450,000	900,000	675,000	940,000
Vermont,	392,000	480,000	700,000	375,000	600,000	430,000	700,000
Massachusetts,	1,008,000	550,000	1,100,000	425,000	1,050,000	680,000	895,000
Rhode Island,	1,226,000	750,000	980,000	350,000	720,000	479,000	670,000
Connecticut,	8,037,000	3,100,000	7,300,000	2,450,000	6,250,000	5,250,000	7,200,000
New York,	8,020,000	2,250,000	5,500,000	1,400,000	3,300,000	3,800,000	4,150,000
New Jersey,	6,872,000	2,220,000	6,550,000	1,500,000	3,500,000	3,100,000	3,275,000
Pennsylvania,	2,977,000	3,150,000	3,800,000	1,900,000	3,400,000	3,260,000	3,515,000
Delaware,	2,873,000	2,100,000	2,100,000	1,250,000	1,400,000	980,000	750,000
Ohio,	3,059,000	2,230,000	2,140,000	1,150,000	2,100,000	924,000	632,000
Wisconsin,	2,165,000	2,000,000	2,250,000	2,450,000	1,400,000	466,000	600,000
Illinois,	1,071,000	1,100,000	1,100,000	1,150,000	1,000,000	450,000	540,000
Missouri,	1,043,000	850,000	850,000	900,000	1,250,000	1,306,000	1,550,000
Kansas,	937,000	1,000,000	1,000,000	950,000	1,000,000	800,000	1,100,000
Nebraska,							
Iowa,							
Arkansas,							
Colorado,							
Idaho,							
Utah,							
Montana,							
California,	1,162,000	1,200,000	1,200,000	1,200,000	1,100,000	1,150,000	865,000
Oregon,							
Washington,							
West Virginia,							
Virginia,							
Maryland,							
Kentucky,							
Tennessee,							
All other,	16,481,000	16,700,000	18,100,000	8,500,000	16,455,000	17,846,000	16,573,000
United States,	58,466,000	37,460,000	56,820,000	26,970,000	46,625,000	42,626,000	45,369,000

Table III—Continued.

State.	Estimate of American Agriculturist.					
	1905.	1906.	1907.	1908.	1909.	1910.
Malne, -----	Barrels, 630,000	Barrels, 900,000	Barrels, 1,700,000	Barrels, 625,000	Barrels, 950,000	Barrels, 850,000
New Hampshire, -----	600,000	710,000	800,000	500,000	400,000	600,000
Vermont, -----	350,000	600,000	750,000	375,000	200,000	550,000
Massachusetts, -----	525,000	700,000	600,000	450,000	500,000	350,000
Rhode Island, -----	100,000	100,000	100,000	125,000	100,000	100,000
Connecticut, -----	450,000	275,000	400,000	250,000	200,000	300,000
New York, -----	3,330,000	5,200,000	4,650,000	4,500,000	4,100,000	3,200,000
New Jersey, -----	750,000	650,000	400,000	350,000	400,000	350,000
Pennsylvania, -----	2,100,000	3,750,000	3,000,000	2,000,000	2,000,000	1,600,000
Delaware, -----	150,000	180,000	150,000	200,000	150,000	200,000
Ohio, -----	650,000	2,750,000	1,800,000	1,000,000	1,050,000	850,000
Michigan, -----	1,800,000	3,500,000	1,900,000	1,600,000	2,250,000	1,400,000
Wisconsin, -----	100,000	250,000	200,000	250,000	150,000	150,000
Indiana, -----	510,000	1,000,000	600,000	500,000	650,000	450,000
Illinois, -----	525,000	2,100,000	850,000	750,000	800,000	250,000
Missouri, -----	400,000	2,275,000	400,000	400,000	540,000	225,000
Kansas, -----	360,000	450,000	125,000	375,000	350,000	200,000
Nebraska, -----	200,000	375,000	140,000	200,000	350,000	200,000
Iowa, -----	365,000	650,000	350,000	425,000	500,000	300,000
Arkansas, -----	550,000	900,000	300,000	300,000	350,000	250,000
Colorado, -----	240,000	300,000	250,000	300,000	450,000	550,000
Idaho, -----	100,000	100,000	200,000	150,000	100,000	200,000
Utah, -----	90,000	100,000	150,000	150,000	150,000	175,000
Montana, -----	25,000	40,000	50,000	75,000	100,000	100,000
California, -----	950,000	1,100,000	1,000,000	1,250,000	1,100,000	1,300,000
Oregon, -----	400,000	500,000	550,000	600,000	300,000	575,000
Washington, -----	300,000	425,000	475,000	450,000	600,000	800,000
West Virginia, -----	1,200,000	600,000	650,000	500,000	450,000	600,000
Virginia, -----	500,000	550,000	700,000	750,000	600,000	700,000
Maryland, -----	1,700,000	250,000	300,000	300,000	275,000	350,000
Kentucky, -----	1,200,000	2,000,000	1,500,000	1,300,000	1,200,000	1,100,000
Tennessee, -----	1,200,000	1,500,000	1,300,000	1,250,000	1,100,000	1,100,000
All other, -----	2,000,000	3,500,000	3,200,000	3,000,000	3,000,000	4,000,000
United States, -----	24,310,000	38,280,000	29,540,000	25,850,000	25,415,000	23,825,000

a. Error in addition is that of the American Agriculturist. Should be 24,340,000.

Need of Better Knowledge.

Part of the failure to increase in production, indicated in Table III, is doubtless due to lack of knowledge on the part of those immediately engaged in the industry. Undoubtedly great loss and waste could now be avoided, if only the best of our present knowledge were constantly applied.

But another part of the failure must be attributed to the need of more and better knowledge on the part even of official horticulturists. We need to know more concerning the exact crop requirements of the apple; more of just what constitutes optimum conditions throughout the life of the tree and throughout the entire range of operations from choice of soil to market disposal. We should know more exactly which factors tend to promote and which to hinder such conditions; exactly why and how one practice is beneficial while another is not; and just what the characteristic effects of the various influences are, so that conditions in any given case may be properly diagnosed. Such things incidentally require a more intimate knowledge of the exact composition of the crop and its different parts, and especially more light on the characteristic functions and effects of the various mineral elements concerned. The annual draft upon minerals should also be known, since they are neither capable of being created nor of indefinite withdrawal from the soil.

It is quite evident that the goal outlined above will not be reached in a day. Our problem is especially difficult in the case of the apple because of its perennial and long-time nature. This is no sufficient reason for not facing it directly, making all possible studies and tests immediately upon the apple itself, and supplementing these with the relevant facts and principles that are being established for plants in general. In fact, the importance of the industry demands that this be done.

The effects of such a study, however, will not be confined merely to the apple industry, nor even to horticultural instruction relating to apples. They should tend strongly to develop a far more stable and scientific horticulture in general than that we now have. Much progress has been made, but much more remains to be made. Empiricism, contentment with loose, isolated rules or with statements derived from very limited observation, reliance upon current or local practice rather than upon sound experimentation and the determination of the best possible practice,—all these relics of earlier days should be eliminated. And if the studies outlined should have no other effect than to aid in accomplishing this they would still be eminently worthy.

Necessity for a Broad View.

It will be noted that the subject covered by the present paper is rather broad,—too broad for a complete treatment in a single discussion. We believe, however, that such a view is desirable, in the present stages at least for two reasons. First, because the various factors in orcharding are so inter-related that *the conditions best for securing one desired effect are often injurious in some other direction*. Thus the conditions most favorable for yield are often less favorable for color or size, and *vice versa*. In such a case, the

chief problem is to secure a proper balancing of the various factors concerned,—a problem which might readily be overlooked if either yield or color alone were the sole object of investigation.

Second, a comprehensive view is desirable, as will be seen later, because orchard operations are likely to be without their proper effect unless conducted upon the limiting factor. In any given case, therefore, the determination of the limiter is one of the first things to be done. This requires a broad study,—one that involves all possible influential factors; and many of the wasted efforts in past experimentation have resulted from failure to recognize or properly provide for this fact.

THE PRESENT PROBLEM AND ITS FACTORS.

In our present paper, the specific problem before us is a study of the causes or factors influencing certain phases of apple production. We wish to know how the yield, color, average size, and growth of apples may be affected. What are the characteristic effects of the various factors concerned, which factors tend to promote, which to hinder, and which are inactive or neutral regarding the proper development of apples in these respects. Upon these and their related questions, some of which have been indicated above, we have been working during the past four years, and the chief results are recorded here.

In most cases in the present treatment, we have separated the possible factors into their two general classes,—environmental and internal. Both of these classes of influences must always be considered in attempting to understand any observed difference in an orchard.

Among the environmental factors, we have included the usual requirements of autotrophic plants, viz., moisture, light, plant food, temperature, carbon dioxide, and oxygen. Certain minimum amounts of each of these are required in order that any growth may occur. In the case of the apple, however, external conditions are further complicated by the influence of soils, climate, cultural methods, pruning, intercrops or covercrops, altitude and latitude, and certain living agents, such as fungi, bacteria, insects, and rodents. Also the rather uncertain influence of stock upon bees, pollination influences, and even the planting distance or amount of crowding,—all are involved under environmental factors, and each may have its effect.

The internal factors are less definable. Their existence is apparent, however, in the fact of varieties, and often in the otherwise unaccountable appearance of markedly different individuals or mutations within a variety, a number of instances of which are cited in the following pages. They can be distinguished with certainty only by eliminating all other possible causes and by determining whether or not the variations are inherited. Such variations,—due to internal causes,—are doubtless much more common than is ordinarily supposed, despite the fact that many apparent mutations have proved upon test not to be inherited. Whenever favorable mutations can be located, however, their importance is very great. In such cases the force of heredity produces effects, without any expenditure upon our part, that might otherwise be attainable only with great difficulty or not at all.

The "Optimum" Principle.

In dealing with so many factors, it is essential to have a working hypothesis. Some unifying principle is needed to guide one's action and to assist in understanding things otherwise hazy. Such a principle or hypothesis has been worked out in connection with other plants. It may be illustrated by the studies upon the big bamboo in Japan and Ceylon. When this plant was studied by Shibata in Japan, it was found that growth varies with temperature. But when studied by Lock in Ceylon, it appeared that growth follows the moisture supply. Bringing these two facts together, it became evident that growth in the bamboo follows variations in the factor that was present in least amount relative to requirements.¹ This principle apparently holds roughly for growth and development in all plants. The so-called "law of the minimum" is a partial expression of it, and a fuller expression is developed below.

In general, it holds that in order to grow at all, plants require certain minimum amounts of certain factors. With progressive increase in the amounts of these necessary factors, growth—or some other physiological result—increases up to a more or less definite point, called the optimum. With further increase in the factors, growth again diminishes, until at another more or less definite point called the maximum, the amount or intensity becomes so great that all growth is stopped. These changes may as a rule be represented by a curve exhibiting minimum, optimum, and maximum points. Such a curve "may be constructed not only for the ash constituents, but also for the organic food, for the action of light, and indeed for all factors or agencies which produce a perceptible effect only at a certain degree of concentration, above which their action gradually increases until the optimal effect is produced."²

A fair statement of the principle, therefore, is that plant growth increases as all factors approach the optimum. Thus, a decrease from the maximum evidently may promote growth just as effectively as an increase from a minimum. We suggest, therefore, that the "law of the optimum" is much closer to the facts and a better name for the principle involved than the so-called "law of the minimum," which has been attributed to Liebig.

The experimental and practical importance of this appears in the fact that the one factor farthest from its optimum, either below or above, may essentially control the results from a crop. In the past, the factors below their optimums have received most of the attention, though excesses in some other factors may have been the limiters at times when the lower factors were being varied. The excesses are more frequent than is generally supposed. Thus in Arizona, excessive light is frequently the chief crop-limiter. In Colorado, according to Headden,³ certain areas are barren because of too much nitrogen. Excessive moisture may be the limiter, as is usually the case in our poorly drained lands. In some orchards, moreover, in the writer's judgment, the limiter has been excessive pruning.

From all viewpoints, therefore, a complete statement of what we may call the "optimum principle," or the optimum hypothesis, is that

¹See article by F. F. Blackman on "Optima and Limiting Factors," *Annals of Botany*, April, 1905, pp. 281 to 295.

²Pfeiffer. *Physiology of Plants*, I. 413-414.

³Headden. *Colorado Bul.* 155, 1910.

plant growth and development increase as the most distant essential factors approach the optimum. This is essentially the principle upon which most of our orchard experiments have been organized.

Some Experimental Rules and Precautions.

This is a phase of our subject into which the writer hesitates to enter, partly because in so doing we may be "carrying coals to Newcastle." It is such a common experience, however, in looking over results of experiments, to find satisfactory conclusions impossible on account of defects in the original plan, that we have decided to call attention here to some of the more important rules and precautions which in our judgment should be considered in the establishment of a satisfactory set of orchard experiments. Some of these points have been particularly impressed upon us since the beginning of our experiments. In most cases, however, they were considered, and incorporated in our experiments. At the risk, therefore, of offering some unnecessary advice, we make the following suggestions:

(1). The experiments should be sufficiently checked.

What constitutes sufficient checking varies with the kind of experiment. In fertilizer tests, checks are especially necessary. All such experiments should not fail to have a check at each end of the series and others distributed among the treated plots at least one every fourth or fifth plot. If the soil or other conditions are noticeably variable, it will be best to make every third plot a check. Fewer untreated plots than this only lead to doubt in the end, and make it impossible to say just what factors were operative in bringing about the observed differences. In spraying experiments containing several treatments, usually fewer checks are available without unduly exposing some of the treatments to unsprayed conditions. At least a check at each end should be provided, however, and ordinarily this is enough. In some other types of experiments, such as comparisons of cultural methods, the various treatments may be so arranged that no regular checks are required.

(2). Only one factor should be purposely varied at a time.

In other words, the questions considered should be kept clear and distinct, with no overlapping, and with all other factors kept as uniform as possible. For example, if one is trying to determine the influence of plant food upon yield, all questions of time of application, different amounts, or of varying proportions of ingredients should be rigidly excluded, so far as experimental variations are concerned; or else they should be relegated to distinct portions of the experiment.

(3). In general, the early work should be a qualitative study of factors rather than quantitative.

This simply means that we should first try to isolate the limiters, or determine which are the influential factors, before attempting to measure the exact influence of any one. On account of the frequent reversals in our preconceived opinions, it needs to be comprehensive enough to give all possible limiters a chance to operate. After the

limiters are isolated, the quantitative study may begin, with the idea of bringing out especially the optimum conditions of the factors found important. Failure to distinguish clearly between these qualitative and quantitative phases, or the attempt to study the latter before the former, are important causes of failure and wasted efforts in many experiments.

For making a really thorough quantitative study, probably the best general plan is the "triangle method" of fertilizer application proposed by Schreiner.¹ It would have to be modified considerably, however, to make it practicable for orchard trees.

(4). The differences in treatment should be distinct.

By this we mean that the experimental variations should be large enough to practically guarantee evident differences in results, if the factors being tested have any influence. In other words, the investigative net should not be too fine-meshed, at least not until some of the larger points have been definitely established. This fault has appeared in some of the more recent experiments that have come to our attention.

(5). The plots should be large enough to eliminate individuality of the trees, and to provide, at least partially, against loss during the progress of the experiment.

Just how many trees will be required for this evidently can not be stated. But at least 10 trees per plot should be provided, and more are preferable, especially if more than one variety is involved.

(6). Special provision should be made to prevent the tree roots of one plot from foraging upon the other plots.

This is a fruitful source of confused data. The provision is probably best accomplished by having an unconsidered row between all plots, and if there is much danger of surface washing it is the only safe way. If the experiment is already large, however, this method is often impracticable. In such cases probably the best thing to do is to arrange the trees in two or more rows per plot, locate the plots with reference to slope so as to largely or wholly avoid cross-leaching, and then keep the feeding roots within bounds by deep plowing and subsoiling in the middle of the interspaces between the plots.

(7). For greater convenience and uniformity, the number of trees in all plots should be the same, throughout any given experiment.

This avoids some of the computations required when the plots are irregular, and thus reduces the chances for error, besides keeping closer to the actual field results.

(8). Sufficient time should be allowed, before definite conclusions are attempted.

At present, the writer is unable to say just what amount of time is sufficient, in connection with apples. Certain things, such as the usual biennial bearing habit and the formation of fruit buds during

¹This method has been devised by Oswald Schreiner of the United States Bureau of Soils, especially for use in general farm crops. (See Bureau of Soils Bul. 70: 16-19, 1910).

the preceding season, make relatively long periods necessary. Ten years have been allotted for our present experiments, which are now in the fifth year.

An approximate test for the sufficient duration of an experiment may be when effects of the treatment have become fairly constant. This however is yet to be demonstrated, and at least two or three years additional after the effect has become apparently constant, or a number of duplicate tests, will usually be required to determine the actual constancy of an effect.

Other important requisites will readily occur to the reader, such as sufficient duplication, thorough and permanent charting and labeling of trees, avoidance of incompatibles in the fertilizer mixtures,¹ adaptation of treatments to the particular demands of the crop, adjustment of treatments so as to throw light upon current practice, and especially the avoidance of any material change in plan after the experiment is once well started.

With the observance of these precautions in laying out field experiments, we believe that more satisfactory progress will be made, with less disappointment to all concerned.

GENERAL TYPES AND EXTENT OF THE PENNSYLVANIA ORCHARD EXPERIMENTS.

The original data herein recorded are obtained, as stated above, from experiments started by the writer, in the spring of 1907 and 1908, acting for the Pennsylvania Experiment Station. Most of the data are taken from the older experiments, Numbers 215 to 221. A general description of these experiments in their early stages was given in the Pennsylvania Annual Report for 1907-8, pages 192-198. Additional notes and results for the first three years have appeared in our Annual Reports from 1908 to 1910 and in Bulletins 91 and 100. The latter account summarizes the important results obtained up to the close of the third year. Such portions of these publications as seemed necessary to an understanding of the work as a whole are repeated here, though in case of doubt the reader is referred to the earlier bulletins and reports.

In the present report, data for four years are given; the plan of presenting it is somewhat extended, other experiments and other phases of these same experiments are considered, and results obtained elsewhere are brought into the discussion with much greater fullness than has been done heretofore; also the approximate composition of the fruit and vegetative parts of the apple, and the annual draft per tree and per acre have been worked out, and they are presented herewith, together with our present knowledge of the characteristic functions of some of the more important minerals found in plants.

The types of our experiments upon apples that are now in operation are as follows: (1) The influence of plant food as affected by fertilizers; (2) the influence of different methods of soil management, with and without manures; (3) the influence of various cover crops and intercrops upon tree-growth and fruitfulness; (4) the influence of cion-selection from superior individuals; (5) the influence of different stocks; and (6) the influence of varieties. Besides these larger and more direct experiments, we have others: (7) on the cause of injuries following certain fertilizer applications; (8) value of certain

¹See Experiment Station Work, III, No. 16, p. 421, 1910.

applications in borer-control; and (9) a continuation of our past work upon spray materials and their use. It is with the first four types that we are especially concerned in this report, although some reference is made to most of the others.

Including the work at State College, we now have in operation a total of eighteen experiments, in twelve orchards, located in various parts of the state. These experiments involve ten soil types, 3,660 trees, and cover 91 acres. Forty-nine acres, including 2,219 trees of twelve varieties, are in partial or full bearing.

Since the experiments were started, they have produced 829,527 pounds of fruit. This fruit has been studied from three view-points. Besides the work with the fruit, studies have been made upon wood growth, root-distribution in the different soils and varieties, and upon leaf-weights as an index to the effect of fertilizer applications. The use of leaf weights was given up after the third year, after collecting, drying and weighing many thousands of leaves from the various treatments. This was because of the fact that the average leaf weights showed no definite correlation with fertilizer applications, though their color, relative abundance, and persistence on the trees, as well as other characters, showed marked correlation.

The exact locations, soil types and varieties involved in the experiments away from the College are shown in Table IV.

TABLE IV.—LOCATION AND OTHER DATA ON EXPERIMENTS AWAY FROM THE COLLEGE.

Ex. No.		Owner of Orchard.	Soil.	Varieties.	Age, 1910.	Number of Trees.
215	Adams, -----	Tyson Brothers,	Porter's (?) loam.	York Imperial and Stayman Winsep.	Yr. 11	100
216	Franklin, ---	D. M. Wertz,---	Montalto fine ¹ sandy loam.	York Imperial and Jonathan.	11	160
220	Bedford, ----	Mrs. S. B. Brown,	DeKalb stony loam.	York Imperial and Baldwin.	12 & 22	160
217	Franklin, ---	J. H. Ledy, ---	Montalto loam ¹ ,	York Imperial and Gano.	17	358
218	Franklin, ---	J. A. Nicodemus,	Hagerstown clay loam ¹ .	York Imperial and Albemarle.	11 & 15	400
219	Bedford, ----	J. R. Sleek, ----	Frankstown stony loam.	Y. Imperial, Jonathan, Ben Davis and Gano.	8	320
221	Wyoming, --	F. H. Fassett,--	Chenango fine sandy loam. ¹	Northern Spy and Baldwin.	38	115
336	Chester, ----	A. D. Strode,---	Chester loam,---	Grimes, Smokehouse & Stayman Wine-sap.	8-10	120 & 105 ²
337 ³	Mercer, -----	St. Paul's Orphans' Home.	Volusia silt loam. ¹	Northern Spy, Baldwin & Rome.	3	180 & 180
338	Lawrence, --	J. B. Johnston,--	Volusia silt loam. ¹	Baldwin, -----	22	80 & 105
339	Bradford, --	F. T. Mynard,--	Lackawanna silt loam.	Baldwin and Falla water.	16	120 & 16

¹ Soils not mapped as yet but probably closest to the types indicated according to the observations of O. F. Shaw and H. J. Wilder. All these soils are described and discussed below, immediately after the descriptions of experimental plans.

² In the two sets of figures in this and the following experiments, the first gives the number of trees under fertilizer treatment, the second those under different cultural methods. In experiment 339, the later includes only the sod mulch plot.

³ Trees set out in connection with these experiments, hence not yet in bearing.

The first three experiments, 215, 216 and 220, comprise what may be called our straight fertilizer experiments. Each contains 16 plots of 10 trees each, making a total of 480 trees. The next four are experiments upon cultural methods, with and without manures. They contain from 14 to 50 trees per plot and make a total of 1,193 trees. The last four experiments are a combination of fertilizers and cultural methods. They contain from 8 to 45 trees per plot and make a total of 906 trees.

Plan of Fertilizer Experiments.

The general plan of our fertilizer experiments is given in Figure 1.

I. Check. (No treatment.)
II. Nitrogen and phosphate.
III. Nitrogen and potash.
IV. Check.
V. Phosphate and potash (in muriate form.)
VI. Phosphate and potash (in sulphate form.)
VII. Check.
VIII. Nitrogen, phosphate and potash.
IX. Nitrogen.
X. Check.
XI. Phosphate (in form of acid phosphate.)
XII. Phosphate. (In form of "floats.")
XIII. Check.
XIV. Stable manure.
XV. Lime.
XVI. Check.

Figure 1. Plan of experiment on influence of fertilizers.

In this experiment, each plot contains 10 trees, usually of two varieties.

The nitrogen, phosphates and potash are applied at the rates of 50 lb. of N, 100 lb. of P_2O_5 , and 150 lb. K_2O per acre, in all cases. The nitrogen is applied in the form of nitrate of soda and dried blood, in such amounts as to carry about equal quantities of N in each. This is primarily to prolong the effect over more of the season, and perhaps reduce danger of leaching, since the N in dried blood is less readily available than in nitrate of soda. As indicated in Figure I, plots V and VI compare the muriate and sulfate as carriers of potash, and XI and XII compare acid phosphate and "floats" as carriers of phosphorus. The manure is applied at the rate of 12 tons per acre and the lime at 1000 pounds per acre. All applications are made annually. Four of these experiments are in operation, one of them being on young trees located at the College. The locations, numbers of trees, kinds of soil, etc., in the other three fertilizer experiments, are given above.

Plan of the Experiments on Cultural Methods and Manures.

The general plan of our experiments on cultural methods and manures is given in Figure 2.

I. Clean Tillage. 40 trees.	IV. Tillage and cover crop. 40 trees.	VII. Sod-mulch. 40 trees.	X. Sod. 40 trees.
II. Tillage and Manure. 20 trees.	V. Tillage, cover-crop and manure. 20 trees.	VIII. Sod-mulch and manure. 20 trees.	XI. Sod and manure. 20 trees.
III. Tillage and commer- cial fertilizer. 20 trees.	VI. Tillage, cover-crop and commercial fertilizer. 20 trees.	IX. Sod-mulch and commercial fertilizer. 20 trees.	XII. Sod and commercial fertilizer. 20 trees.

Figure 2. Plan of experiments on cultural methods and manures.

In most cases, since so many trees are required, we have been compelled to modify this plan somewhat, both in numbers of trees and in arrangement of plots, in order to make it fit the conditions available. The essentials, however, have not been disturbed. As indicated in our discussion of experimental rules above, the plan of this experiment might be improved by making the number of trees uniform in all plots throughout the experiment, though the deviation here is not serious.

The locations, soils, numbers of trees, etc., are to be found in Table IV and its following discussion. As shown in the figure, this experiment tests four methods of soil management, viz., clean tillage and covercrop, sod-mulch, and sod. Each treatment occurs both without fertilization and with it in two forms. The stable manure is applied annually at the rate of 12 tons per acre. The commercial fertilizer is a so-called "complete" one and is applied at the rate of 30 pounds N, 60 pounds P_2O_5 , and 100 pounds K_2O per acre. More actual plant food is thus being applied in the manure, since 12 tons of average stable manure are estimated to contain about 120 pounds each of N and K_2O , and about 80 pounds of P_2O_5 . At present retail prices, the fertilizer application costs \$12.35 per acre.¹

On the mulch plot, all herbage remains in the orchard, the first cutting being raked to the trees, as a mulch, and an additional mulch of old straw, swamp hay or buckwheat straw at the rate of about 3 tons per acre is applied annually. In this latter respect, it differs from the so-called "Hitchings plan," and, as a conserver of moisture, it is undoubtedly very much better. On the sod plot, the first cutting of herbage is removed from the orchard and the second is left where it falls. The tillage plots are all cultivated from May until about the

¹A 30-50-50 application per acre, costing about \$9.75, would probably give equal results; and even this cost could be reduced to about \$4.50 per acre by getting the nitrogen through green manuring crops. The real economy of the latter operation will depend upon cost of labor, seed, ease of getting a stand, &c.

middle of July, when those receiving the cover crops are seeded to crimson clover, hairy vetch, or medium red clover and alsike, either singly or in combination. An effort has also been made to keep some leguminous plants in the permanent cover used in experiments VII to XII, though not with as much success as desired.

Plan of the "Combination" Experiments.

These experiments are a combination of certain portions of the two types just described. They are rather more general in their scope, and they aim at two factors instead of one. The general plan is shown in Figure 3.

I. Check. (No treatment) 10 to 15 trees.
II. Nitrogen and phosphate. (No. of trees uniform in plots I to X.)
III. Nitrogen and potash.
IV. Check.
V. Phosphate and potash.
VI. Nitrogen, phosphate and potash.
VII. Check.
VIII. Stable manure.
IX. Lime.
X. Check.
XI. Tillage and covercrop. 30 to 40 trees.
XII. Sod-mulch. 30 to 40 trees.
XIII. Sod. 30 to 40 trees.

Figure 3. Plan of "Combination" Experiments on Fertilizers and Cultural Methods.

The applications in this group of experiments are the same as in the fertilizer experiments described above. The treatments of plots XI to XIII are the same as described for the similar plots in the cultural method experiments. Some slight modifications in this general plan were also found necessary in the installations in orchards already set. In experiment 337, which was set out in connection with these experiments, an additional plot was included. Its purpose is to test the effect of intercrops upon the trees during the early years. The locations, soils, varieties, etc., are stated in Table IV, and in the following discussion.

Description of Soils Involved.

In Table IV, the technical names of the soils involved in our experiments are given. In the present section, these soils are described, their approximate extent and location are indicated, and the chief facts in the previous treatment of the various experimental areas are given. The naming of the soils, and their technical descriptions and approximate extents, have been secured with the aid of H. J. Wilder of the U. S. Bureau of Soils, and C. F. Shaw, who is

also connected with the Bureau and is in charge of the soils work in The Pennsylvania State College. The soils are referred to in connection with their experiment numbers.

Expt. 215. The soil in this experiment has been mapped as Porter's loam, which it resembles, but both Wilder and Shaw agree that it is a different series from the Porter soils. The former has proposed that the name of that series be changed to Floradale, and is using this name in his report on fruit soils. This name, however, has not been approved as yet. The largest areas of it are found in Adams County although some small patches occur in York County. It is generally considered a good fruit soil.

The surface soil consists of a heavy loam or clay loam, brown or dark gray in color, from 6 to 15 inches deep. The subsoil consists of pale red or light brown clay loam or clay. From 15 to 25 per cent. of stones and angular rock fragments are usually present in both soil and sub soil but they are never of sufficient size to materially impede cultivation.

The previous treatment received by the trees in this experiment was as follows: An intercropping system, consisting of potatoes one year followed by timothy and clover two years, had been the practice. A gradually widening strip about the trees was given annual cultivation. The hay was plowed under in the fall and the space between the tilled strips was planted to potatoes in the spring, with the addition of about 1,000 pounds per acre of a 0-12-10 fertilizer in the potato rows. The orchard was in the second year of the hay crop when our experiment started.

Expt. 216. The soil of this experiment is much like the more widely distributed DeKalb soils, but is sufficiently different to be classed separately under the title of Montalto fine sandy loam. This series occurs along the north slope of South Mountain and is found best developed in Franklin and Berks Counties. The soils occur as slopes on the lower flank and foot of the mountain and are derived from iron stones, quartzites, cherts and other rocks. They are locally known as ironstone lands. One of the characteristics of this soil is the tendency to become sticky when wet which makes it hard to plow.

The soil had been cropped in general farm crops for many years, with moderate success before being set to fruit. The filler system with peaches is the treatment that had been in use in the orchard, and during the later years moderate annual dressings of bone and sulphate of potash had been applied to the peach trees. It is generally considered to be a very good fruit soil, especially for peaches, some striking successes having been made upon similar locations in this valley.

The surface consists of 6 to 8 inches of a yellowish brown or reddish yellow, gritty or sandy loam resting on a loose reddish yellow loam subsoil, which grades into a somewhat sticky loam or clay at the depth of 24 to 36 inches. Soil and subsoil contain 30 to 60 per cent. of fine angular chert fragments.

Expt. 220. As stated in Table IV, this soil is DeKalb stony loam. Considerable areas are found in Lancaster, Lebanon and Montgomery Counties in Pennsylvania.

The surface soil consists of brown, yellow, or gray, medium sandy loam from 6 to 10 inches deep. The subsoil ranges from heavy yellow

sandy loam to light red clay loam, resting upon a mass of sandstone and quartzite fragments. Both soil and subsoil contain a large quantity of sandstone, conglomerate and sandy calcareous shale fragments.

Locally, the soil of this experiment would be described as a shallow, very stony, foothill soil, immediately underlaid by such masses of sandstone and quartzite as to have the effect of solid rock. It had been cropped for many years, until it is said to have become so poor that it would not produce five bushels of corn to the acre, nor return the seed sown for oats. Despite this, the Yorks have produced profitable crops, and supported the family. When our experiment started, however, both fruit and twig growth were small. It appeared to be a soil that had been cropped into almost complete unproductiveness, first as a producer of field crops and then as a producer of fruit; hence it seemed a favorable situation in which to test the influence of fertilizers on apples.

Expt. 217. The soil in this experiment has been designated as Montalto loam. Its description and discussion are the same as that given above for 216 with the exception that, being a loam, it does not contain so much sand and grit.

Expt. 218 As indicated in Table IV, the orchard of J. A. Nicodemus is located upon a Hagerstown clay loam soil. This is a residual, limestone soil. The soil is a heavy, reddish, silty loam, averaging about 24 inches in depth, overlying stiff, tenacious, red clay. The type occupies rolling valley land and is derived from the weathering of pure, massive limestone. No fertilizer had been applied to the trees in so far as we were able to learn.

This soil is practically the same as that found in our Experiment Station farm at State College. It is described by C. F. Shaw, in our Annual Report for 1907-8 pp. 69-70, as follows. "The surface soil of the Hagerstown clay loam consists of from 6 to 8 inches of rather light and silty clay loam of a yellow-brown to red-brown color. The subsoil consists of a medium to heavy red clay which grows heavier and stiffer with depth. The soil section in most cases contains from 5 per cent. to 15 per cent. of small angular chert and limestone fragments. It is easily cultivated and the drainage, both surface and underground, is good."

Expt. 219. The soil in J. R. Sleek's orchard was called DeKalb shale loam in our Bulletin 100, but in the recent survey of the county it has been named Frankstown stony loam. The so-called Chestnut Ridge in Bedford County is one of the largest known areas, and smaller areas are found in Perry, Juniata and Mifflin Counties. There are probably not over 100 square miles in this series. The soil is locally reputed to be the best in Bedford County for the production of corn and rye. It is said never to "cake" and to be always friable, regardless of amount of moisture contained when tilled.

The surface soil is a gray silt loam, 6 to 8 inches deep, resting on a light gray sandy loam which grades into a yellow loam at 36 inches. The soil and subsoil contain 20 to 60 per cent. of flat gravel or angular rock fragments locally known as "bastard limestone." Where it occurs, this soil occupies one slope of a ridge, the top and opposite side of which is derived from the true limestones. In other cases, where underlying rocks do not stand at a sharp angle, the soils may occupy the whole of a rounded or eroded ridge.

Expt. 221. The soil type found in this experiment, which heretofore has not had a series name, has been named Chenango by H. J. Wilder, and as such appears in his fruitsoils report. It has apparently been deposited in a temporary lake bed, formed by the partial stoppage of the Susquehanna River in cutting through the mountains. There is a considerable amount of such soils along the streams in this part of Pennsylvania. It is considered good fruit land. The surface soil is a sandy loam. The subsoil is a yellowish fine sandy loam for about two feet. This is underlaid with sand, becoming gravelly and continuing to a depth of about 30 feet.

The previous treatment of this orchard was as follows. The trees were set in the spring of 1873. It was cultivated for the first 12 years and intercropped with potatoes, with the exception of corn two years and beans one year. It was then sowed down for two years, replowed in 1887, and sowed in oats one year. In 1888, it was in buckwheat and was sowed to clover, in which it remained until 1898. During this time it was manured every other year at the rate of about 500 pounds per tree, one-half of the orchard being manured one year and the other half, the next.

In 1898, the west half of the orchard was plowed and sowed in cowpeas. The effect on the trees was so favorable that since then the orchard has been plowed every other year, one-half being plowed each year and the other half remaining in crimson clover sown as a cover crop. The manuring continued as above. These operations continued until 1907. When first seen by the writer, the part of the orchard used for our experiment was in clover and red top.

Expt. 336. This soil is predominatingly Chester loam although both loam and heavy silt loam of the Chester series are found in the orchard. This series occurs in the northern part of the Piedmont having been found and mapped only in Pennsylvania, Maryland and Virginia. In the U. S. Bureau of Soil's Survey of Chester County, it is said to comprise about 41 per cent. of the county. It has been formed principally by the breaking down of gneisses, aided to a less extent by residues from mica schists. The mica often gives a decided sparkle to the soil of this vicinity and should indicate an abundant potash supply.

In general, the surface soil in Chester loam consists of a mellow, brown or yellowish loam, sometimes slightly sandy, containing some mica. This is underlaid by a heavy yellow loam subsoil grading into clay loam, which in lower depths becomes somewhat lighter in texture and more micaceous. The color is sometimes reddish yellow or red.

The soil is well adapted to general farming, corn, oats and wheat being raised successfully. Its adaptation for fruits appears good, judging from the large growth and early bearing of the trees in Mr. Strode's orchards; and also from the success of pears in the neighborhood, especially Seckels. The large nursery industry of the county is also being conducted almost entirely on this soil.

Expt. 337-338. In the opinion of H. J. Wilder, the soils of these two experiments are probably Volusia silt loam, as named in Table IV. The Volusia soils are found in eastern Ohio, southern New York and northern Pennsylvania.

The soil of the Volusia silt loam, to an average depth of 8 inches, is a gray to a brown silty loam. The subsoil, to a depth of about

Expt. 331 (288 trees) Cultural Methods.

Exp. 409 (18 tr.) Borer Control.

Exp. 408
(24 tr.)
Fertilizer Injury

Expt. 332. (192 tr.) Fertilization.

II Clean Tillage until bearing, then sod	I. Check	I. N. Spy
	II N. P.	II Tolman
	III N. K.	III Wolf River.
VII Mulch	IV Check	IV Paragon
	V P. K.	V Champion
	VI PK_2SO_4	VI Nursery Trees
XIII Mulch and Manure	VII Check	I Medium Red Clover
IX Mulch and Comp. Fertilizer	VIII N. P. K.	II Alsike and Crim. Clover.
IV Tillage and Cover crop	IX N	III Hairy Vetch.
	X Check	IV Cowpeas Soy Beans
	XI Acid Phos.	V Oats and Canada Peas
III Tillage and Intercrop	XII Raw Phos.	VI Rye
	XIII Check	VII Millet
V Tillage, Covercrop and Manure	XIV Manure	VIII Rape
	XV Lime	IX Buckwheat
VI Tillage, Covercrop and Comp. Fertilizer.	XVI Check	X Alfalfa

Expt. 334.
(72 tr.)

Stocks and
Top-working,
(For Grimes,
King and
Jonathan)

Expt. 335 (360 tr.)
clover - selection,
and
variety test.

Expt. 333
(120 tr.)
Covercrops
on growth

Fig. 4. Expts. in Progress in the Expt'l Apple Orchard at State College, Pa.

two feet, is a light, yellow, silty loam, and below two feet, it usually becomes mottled with gray or drab. A considerable quantity of finely divided shale fragments are found in both soil and subsoil. It is called locally a friable clay soil, underlaid at a depth of about two feet by "hard-pan." It is usually in need of drainage, though this is not especially evident in experiment 338.

Expt. 339. This soil resembles those of the Upshur series in some respects and was so named in our Bulletin 100. This past summer, however, it was named Lackawanna silt loam by the men who made the soil survey of Bradford County. This series covers considerable areas of the upland portions of the northeastern part of this state. It is a glaciated soil.

The surface soil is a decidedly silt loam of varying shades of red resting on a dark red silty clay subsoil derived from feeble glaciation of red sandstones and shales. The series, as a whole, has a rolling topography and good drainage. The surface and subsoil contain large amounts of flat stones derived from the underlying rocks.

Some previous fertilization had been given to a part of the trees in this orchard. It consisted of wood ashes, and later of a local "fruit fertilizer" reinforced with muriate of potash. Grass, with occasional crops of buckwheat in which the crop was harvested, was the previous practice in the orchard.

Orchard Experiments Located at the College.

The principal orchard experiments now in operation at The Pennsylvania State College are indicated in Table V. A preliminary experiment on pruning has also been started, but is not listed because of more comprehensive work to be undertaken later.

Table V.—ORCHARD EXPERIMENTS LOCATED AT THE PENNSYLVANIA STATE COLLEGE.

Expt. No.	Subject Under Experiment,	Varieties Involved.	Number of Trees.
331	Cultural methods, ...	York Imperial, Stayman, Winesap, Baldwin.	288
332	Fertilizers, ...	York Imperial, Stayman, Winesap, Baldwin.	192
333	Cover crops, ...	York Imperial, Stayman, Winesap, Baldwin.	120
334	Apple stocks, ...	Indicated below, ...	72
335	Varieties and cion-selection, ...	Indicated below, ...	360
408	Fertilizer injury, ...	Indicated below, ...	24
409	Prevention of borers, ¹	Indicated below, ...	18

The general plans and arrangement of these experiments are shown in Figure 4.

The trees in this orchard were set in the spring of 1908. They cover 28 and two-thirds acres. Allowing for some that are counted twice, they number 1,032 trees. One-year-old Northern Spy trees were used as the stock in the first two experiments, 331 and 332; and two year old Spy for about 135 trees of experiments 334 and 335. The trees of two rows of the latter were considerably affected with hairy root.

¹This experiment is also being conducted upon peaches, in which a total of 20 trees is involved.

now known to be one phase of the crown gall disease.² They were obtained too late to get other trees, however, so we thus have incidentally an opportunity for making observations on the field behavior of this interesting disease.

The trees of experiments 331 and 332 were top-worked in the spring of 1909 with the varieties indicated in the table, using cions of a single tree to the row in most cases. For most rows, the cions used were selected from single superior trees, which is also the case throughout experiment 334. The selection phase of our work, therefore, overlaps some of the other experiments, but it is done so as to be uniform for all treatments and thus not to confuse the results from either viewpoint. This accounts, however, for some of the trees being counted twice, as indicated above.

The age of the trees and the duration of these experiments are too brief for any important results as yet. Such data as appear to be valuable, however, are given later in their appropriate connections. These cover especially the present progress in our work upon certain fertilizer injuries and upon cion-selection.

General Plan of Present Paper.

In the present treatment of our subject, some of the principal factors are considered twice, first from the viewpoint of the factors; and second, from that of the effects. In other words, each factor, on which we have data, is first considered in connection with its various effects; and then some of the effects, such as size or color, are considered, each in connection with the various factors that may be expected to affect it. As will be observed, most of the data on these points are original. Also much of that from the experiments or reports of others has been re-assembled or re-calculated, often from somewhat different viewpoints.

The direct results of our experiments up to the time of the present report are given in pages 455 to 504. The results on any particular phase can be found most readily by consulting the *summary and contents* given on pages 506 to 512.

²See Bulletin-213, U. S. Bureau of Plant Industry, 1911.

PLANT FOOD AS A FACTOR IN APPLE PRODUCTION.

Among fruit-growers and horticulturists generally, there is much difference of opinion as to the value and necessity of plant-food applications to apple trees. The common reasons advanced against their use are: The deep-rooting habits of the trees; the high water-content of the fruit; the long growth season; the long preparation stage before fruiting; and the so-called off years for recuperation. But inasmuch as the off year may frequently be largely overcome by proper fertilization and other care, its existence would seem to be more valuable as evidence in favor of fertilization than as a basis for argument against it. The same is true of the long preparatory stage before fruiting. This long growth period, without chance for rotation, during which considerable quantities of plant food are being locked up in the wood and blown away in the leaves, is likely to be more of a cause for fertilization than for the lack of it. Moreover, it is desirable that this long preliminary stage be shortened, and under optimum conditions this is accomplished.

The supposed deep-rooting habit of apple trees is also apparently over-estimated. This is true of many places here in the east, at any rate. As shown later, in a study of 28 trees of different varieties, in different parts of Pennsylvania and on various soil types, we found that the great majority of the feeding roots were in the surface foot of soil, and only rarely were they found deeper than 18 inches. This condition apparently does not hold for the more arid regions or possibly for some of the looser and dryer soils. But for most eastern soils, where the moisture is usually sufficient for satisfactory growth practically to the surface, the feeding roots evidently seem to prefer the upper layers of the soil. In all trees examined by us, at any rate, these roots were comparatively shallow.

In regard to the high water-content of apples, it is true that the fruit averages about 85 per cent. of water.¹ But it is also true that, in the remaining 15 per cent. of dry matter, more pounds of actual plant food are removed in an average crop of apples than in a similar crop of wheat.² In addition to this, considerable quantities of plant food annually are locked up in the wood of tops and roots and in the leaves, which are likely to be blown away and mostly lost to the orchard unless special precautions are taken.

The Mineral Constituents of Apples.

A fairly exact knowledge of the composition of the fruit and various vegetative parts of apples is evidently highly desirable from many viewpoints. It informs us as to where the various plant food elements go, and hence what parts their lack or addition is most likely to affect. It should thus be useful in diagnosis, in detecting mal-nutrition in the orchard, and in observing and interpreting the results of plant-food applications. Coupled with a knowledge of the approximate annual weights of fruit, wood and leaves produced by a mature tree under average conditions, it also enables us to determine fairly accurately just what is the annual draft upon plant food exerted by such a tree or by an acre of apples.

¹As found later, it is about 81.6 per cent. on the average. See Tables VII, XVII, and XVIII on this point.

²See our Table XXVII for data on this point.

Addressing ourselves to this problem, we first collected a few of the more prominent reports of analyses for comparison. Such marked differences appeared, however, and such important omissions frequently occurred in a single report that we decided to give some special attention to the matters involved.

We therefore collected all the available analyses of apples,—fruit, twigs, leaves, wood and roots,—of which we could find any trace. The American and German results were most satisfactory, both in number of analyses and number of men reporting, and hence our work was confined to them. Most of the American analyses, in the form originally reported, are given in the following tables. The wide diversity in bases of calculation, sometimes two or more bases being used in a single report, made it necessary to recalculate everything to a uniform basis, before comparisons or averages could be made. This we have done, reducing the original data first to the green weight and then to the dry weight basis. The latter basis is preferred and used in all our subsequent computations, but the green-weight tables are also given.

In handling the German results, only the final averages are given here, together with the names of the analysts and the references to their original data. Since their estimates of annual draft are in the units of the metric system, we have given them first as they occur in the original, and then converted them into English units for comparison.

A number of the American and German reports are not included for various reasons.¹ In such cases there were important omissions, making it difficult or impossible to reduce them to uniform bases. Others were not attributed to any particular work or analyst, and were apparently sufficiently covered in the definite reports already incorporated in our tables. Still others were evidently abnormal, a fact which frequently became apparent, however, only after calculation to the common basis and comparison with the majority of other analyses. Where this abnormality affected only one or two items, the reports have generally been given with the affected items inclosed in parentheses and excluded from the final averages.

The Composition of Apples: American Analyses.—The American analyses of apples are presented in Tables VI to XIV. Tables VI, IX, and XII give the data on fruit, leaves, and wood, respectively, as originally reported, with the exception that averages have been made by us where two or more similar analyses are reported by the same man. Tables VII, X, and XIII show the data in their preceding tables recalculated to a uniform basis, that of green weight. And Tables VIII, XI, and XIV show the same data reduced to the uniform basis of dry substance.

¹These omitted results include reports by Hilgard (Cal. Bul. 88); reports in the Handbook of Experiment Station Work (Bul. 15, O. E. S., p. 402); reports in Wolff's *Aschen-Analysen*; also those by Czapek in *Biochemie der Pflanzen* II: 830, 1905; and some of König's results in *Chemie der Menschlichen Nahrungs-und Genussmittel*.

Table VI.—THE COMPOSITION OF APPLE FRUIT.

(American analyses as reported in the publications cited).

Analyst or Author.	No. of Varieties.	Water.	N.	P ₂ O ₅ .	K ₂ O.	CaO.	MgO.	Fe ₂ O ₃ .	Total Ash.
Shutt F. T. ¹ , '94.	4	86.98 %	.0488 %	8.98 %	55.26 %	4.384 %	4.27 %	1.72 %	.98 %
Roberts, ² '95.		85.3 %	.13 %	.01 %	.19 %				
Colby, ³ '98.	16	85.03 %	1.05 lb.	0.33 lb.	1.4 lb.	0.11 lb.			2.64 lb.
Brown, ⁴ '00.	Mixed ash of many varieties.	81. %	.11 % (protein)	.01 %	55.94 %	4.43 %	3.78 %	.95 %	.30 %
Alwood, ⁵ et al '04.	7 (winter)	85.38 %	.046 %	.023 %	155 %	.009 %			.96 %
Van Slyke, ⁶ et al '05.	24	1355 lb. green wt. 185.63 lb. dry wt.	0.573 lb.	.344 lb.	1.48 lb.	.112 lb.	.182 lb.		
Van Slyke, ⁹ et al, '05.	94	85.43	.013	.027	.127				

¹ Canada Experimental Farms Report, page 166, 1894. The ash constituents are given in percents of ash in this case.

² Cornell Bulletin 103: 535, 1895. This analysis is quoted from the handbook of Experiment Station work, Office of Expt. Stations Bul. 13: 402, 1894.

³ Cal. report 1898: 148. Analyses of California apples.

⁴ The following results are calculated or averaged by the writer.

⁵ In this analysis and those following by the same man, the results are given in pounds per 1000 lb. of product.

⁶ Pennsylvania Department of Agriculture, Bul. 58: 9-11, 1900.

⁷ U. S. Bureau of Chemistry, Bulletin 88: 19, 1904.

⁸ Van Slyke, Taylor and Andrews, N. Y. Geneva Bul. 265; Table 1, 1905.

⁹ Ibid, page 224.

Table VII.—THE COMPOSITION OF APPLE FRUIT.

(American analyses, reduced to green weight).¹

Analyst or Author.	No. of Varieties.	Water.	N.	P ₂ O ₅ .	K ₂ O.	CaO.	MgO.	Fe ₂ O ₃ .	Total Ash.
Shutt F. T.,	4	86.96	.0428	.025	.1547	.012	.012	.0043	.23
Roberts,		85.3	.13	.01	.19				
Colby,	16	85.03	.105	.033	.14	.011			.264
Browne,		84.00	.016	.026	.1678	.013	.0113	.0038	.30
Alwood et al,	7 (winter)	85.88	.056	.023	.155	.009			.26
Van Slyke et al,	2	86.3	.023	.018	.11	.0082	.0134		
Van Slyke et al,	9	86.43	.073	.027	.127				
Averages in % of green weight,	38+	85.02	.0671	.023	.1492	.0089	.0122	.0033	.276

¹. (Data of Table VI recalculated to green basis by the writer.)

Table VIII.—THE COMPOSITION OF APPLE FRUIT.

(American analyses reduced to dry substance).¹

Analyst or Author.	Number of Varieties.	Dry Substance, ² %	N, %	P ₂ O ₅ %	K ₂ O %	CaO %	MgO %	Fe ₂ O ₃ %	Total Ash, %
Shutt, F. T., '94,--	4	13.01	.3839	.1921	1.1890	.6922	.0922	.0369	2.163
Roberts, '95,--		14.7	.8343	.0630	1.2925				
Colby, '98,--	16	14.07	.7462	.2345	.9950	.0781			1.876
Browne, '00,--		19	.1000	.1625	1.0487	.0312	.0706	.0175	1.875
Alwood, et al., '04,--	7 (winter)	14.62	.8880	.1573	1.0602	.0615			1.778
Van Slyke, et al., '05,--	2	13.7	.3087	.1314	.8029	.0603	.0978		
Van Slyke, et al., '05,--	9	14.57	.5010	.1863	.8716				
Average, in % of dry substance,-----	38+	14.38	.4646	.1616	1.0371	.0746	.0899	.0194	1.920

¹ Data of Table VI, recalculated by the writer to per cents. of dry substance, except the dry substance itself, which is in terms of green weight.² This column gives the dry substance in per cent. of green weight. In all other columns the values are in per cents. of dry substance.

Table IX.—THE COMPOSITION OF APPLE LEAVES.

(American analyses as reported in publications cited below).

Analyst or Author.	Number of Varieties.	Water.	N.	P ₂ O ₅	K ₂ O	CaO	MgO	Fe ₂ O ₃	Total Ash.
Saunders, ¹ 90	5 (picked May 25-89)	72.36a %	7.42b lb	2.45b lb	2.52b lb	17.4c %	9.77c %	1.49c %	2.22a %
Saunders, 90	5 (picked Sept. 20-89)	60.71a %	8.57b lb	1.91b lb	3.92b lb	27.91c %	4.81c %	1.41c %	3.46a %
Roberts, ² 95	1 (old tree)	139.51 lb	.96 lb	.37 lb	1.32 lb				
Roberts, 95	1 (13-Yr. tree)	47.98 %	1.85 %	.488 %	1.76 %				
Van Slyke, ³ et al., 05	2	34.72 lb	.8655 lb	.1375 lb	.271 lb	1.42 lb	.466 lb		9.53 %
Van Slyke, ⁴ et al., 05	9	54.01 %	.688 %	.696 %	.343 %				
Warrens & Voorhes, 06	1		.97 %	.17 %	.72 %				3.78 %

¹Canada Experimental Farms Report 1890, pp. 141-146 (a)=per cent. of green weight; (b)=pounds in 1,000; (c)=per cent. of ash.²Cornell Bul. 103: 533-541, 1895. All weights are those found in 232.02 pounds of leaves, which is reported as the total weight from one tree in one year. These analyses and all others originally reported in this bulletin were made by G. W. Cavanaugh.³N. Y. Geneva Bul. 265, 1905. All weights are those found in 80.5 pounds of leaves, the average weight per tree for one year; (Averaged by the writer from the data in their table I).⁴N. Y. Geneva Bul. 265, page 224. Results averaged by us.⁵New Jersey Station Report 1906: 204. These results represent the average composition for 10 years, on the Smith Cider variety.

Table X.—THE COMPOSITION OF APPLE LEAVES.

(American analyses reduced to green weight basis).¹

Analyst or Author.	Number of Varieties. %	Water. %	N. %	P ₂ O ₅ %	K ₂ O %	CaO %	MgO %	Fe ₂ O ₃ %	Total Ash. %
Saunders, ... '90,--	5 (young lvs.)	72.36	.742	.245	.252	.4054	.2276	.0347	2.33
Saunders, ... '90,--	5 (older lvs.)	66.71	.887	.194	.392	.9656	.1664	.0487	3.46
Roberts, ... '95,--	1 (old tree)	60.13	.4137	.1595	.569	.....	.....	.....	.....
Roberts, ... '95,--	1 (13-yr. tree)	47.98	.9623	.2533	.9155	.....	.....	.....	.....
Van Slyke, et al., ... '05,--	(43.1)	.....	1.075	.1708	.3366	1.764	.579	.....	4.95
Van Slyke, et al., ... '05,--	9	54.01	.688	.066	.843	.....	.....	.....	.....
Warren & Voorhees, ... '06,--	1 (Average)	.....	.97	.17	.72	.....	.....	.....	3.73
Averages, in % of green weight, ...	(10 years)	50.04	.8197	.1842—	.504	1.045	.324	.0117	3.63

¹ Data of Table IX recalculated by the writer to per cent. of green weight.

Table XI.—THE COMPOSITION OF APPLE LEAVES.

(American analyses reduced to the basis of dry substance).¹

Analyst or Author.	Number of Varieties.	Dry Substance. ² %	N. %	P ₂ O ₅ %	K ₂ O %	CaO %	MgO %	Fe ₂ O ₃ %	Total Ash. %
Saunders, ----- '90	5 (yg. lvs.)	27.64	2.6845	.8461	.5117	1.4377	.8234	.1255	8.4288
Saunders, ----- '90	5 (older lvs.)	39.29	2.2575	.4337	.9977	2.4576	.4235	.1239	8.8062
Roberts, ----- '95	2	45.94	1.4438	.444	1.5235	---	---	---	9.53
Van Slyke, et al., ----- '05	2	(56.9)	1.8892	.3001	.5915	3.1001	1.0175	---	---
Van Slyke, et al., ----- '05	9	45.99	1.4959	.2087	.7458	---	---	---	---
Warren & Voorhees, ----- '06	1 (Aver. for 10 years)	(39.7) ²	2.4433	.4282	1.8136	---	---	---	9.52
Averages in % of dry substance, -----		39.71	2.0357	.4602	1.1089	2.8415	.7549	.1247	9.0715

¹Data of Table IX recalculated by the writer to per cents. of dry substance, except the dry substance itself, which is in terms of green weight.²For calculating to the dry weight basis, the average per cent. of dry substance found below (39.7%) was assumed in the data of Warren & Voorhees. In a recent letter from M. A. Blake, we have learned that the average for the last four years was 42.6%.

Table XII.—THE COMPOSITION OF APPLE TWIGS AND WOOD.

(American Analyses as reported in publications cited below).

Analyst or Author.	Number of Varieties.	Water.	N.	P ₂ O ₅	K ₂ O	CaO	MgO	Fe ₂ O ₃	Total Ash.
Patrick, ¹	1 ²	46.8 %	[6.72 % protein.]						3.87 %
Collier, ³	Nursery stock of 8 kinds	{ 22,183 lb green wt. per acre. 948 gm.		21.4 lb	27.1 lb	138.6 lb	23.7 lb	6.1 lb	399.3 lb
Collier, ³	3 (Nursery stock) ²	grn. wt. 405.6 water		.9107 gm.	1.1 gm.	6.66 gm.	1.413 gm.	2.9 gm.	18.56 gm.
Roberts, ⁴	3 (Nursery stock) ²	7.3 lb grn. 3.91 lb dry	.0218 lb	.0076 lb	.0148 lb				
Roberts, ⁴	1 (old tree)	{ 5251.4 lb grn. 2951.2 lb dry.	8.09 lb	3.07 lb	7.65 lb				
Schweitzer, ⁵	3 (water sprouts)			.23165 %	.9157 %	.9713 %	.0032 %	.0201 %	2.6631 %
Schweitzer, ⁵	3 (bearing twigs)			.46315 %	.9639 %	2.2864 %	.1265 %	.0231 %	4.3313 %
Traphagen, ⁶	9 (new twigs) ²								
Van Slyke, ⁸ et al.,	2 ³		416 % .0135 lb	.011 lb	.016 lb	.085 lb	.016 lb		
Van Slyke, ⁸ et al.,	9 (11 trees) ²	6.102 % (7.03 lb grn. 3.35 lb dry)							
Traphagen, ⁶	9 (older twigs) ²	49.98 % 6.26 %	.448 % .633 %	.146 %	.252 %				
Warren ⁹ et al.,	1 (average 10 years)		.41 %	.14 %	.30 %				1.78 %

¹Iowa Station Bulletin 4: 102-103, 1889.²Following results calculated or averaged by the writer.³N. Y. Geneva Report 1891, pp. 164-171.⁴Cornell Bul. 163, 1895.⁵Calif. Station Report 1898: p. 180. The per cents. given are based upon dry substance.⁶Montana Station Report 1903: p. 34. Twigs collected November 1, 1899 and analyzed January 5, 1900, which doubtless accounts for their low water content.⁷Van Slyke, Taylor and Andrews. N. Y. (Geneva) Bulletin 265, 1905. Average annual growth of twigs.⁸ibid p. 224.⁹Warren, G. F., and Voorhees, J. A. (Miss). N. J. Report 1906: p. 204. A range composition of pruned twigs for 10 years.

Table XIII.—THE COMPOSITION OF APPLE TWIGS AND WOOD.

(American Analyses reduced to green weight basis).¹

Analyst or Author.	Number of Varieties.	Water. %	N. %	P ₂ O ₅ %	K ₂ O %	CaO %	MgO %	Fe ₂ O %	Total Ash. %
Patrick, G. E., '80	4	46.8	.572	.0967	.1165	.7026	.1196	.0308	2.06
Collet, '91	3 (young)	42.78	.30—	.104	.203—	—	—	—	1.965—
Roberts, '95	6 (young)	46.44	.154	.0346	.1437	—	—	—	—
Roberts, '95	1 (old)	43.8	—	.1458	.475	.486	.047	.01	1.83
Schweitzer, '98	3 (water sprouts)	—	—	.2097	.5532	1.326	.0733	.012	2.46
Schweitzer, '98	3 (bearing twigs)	—	—	—	—	—	—	—	—
Traphagen, F. W., '03	9 (young twigs)	(6.102) ²	.2496 ²	.1365	.2276	—	—	—	—
Traphagen, F. W., '03	9 (older twigs)	(6.26) ³	.3235 ²	.146	.30	1.309	.2276	—	—
Van Slyke, et al., '05	2 (twigs of old trees)	32.35	.41	.14	.30	—	—	—	—
Van Slyke, et al., '05	9 (11 trees)	—	.448	.14	.252	—	—	—	—
Warren & Voorhees, '06	1 (average for 10 years)	49.98	—	—	—	—	—	—	1.78
Averages, in % of green weight, -----	50	47.02	.3141	.1169	.2070	.9309	.1244	.0175	1.917

¹Data of Table XII recalculated by the writer to per cent. of green weight.²The following per cents are recalculated from those given in Table XII, assuming that the water sprouts contained 50% of water and the fruiting twigs 42%, the latter corresponding closely to the German analyses given later.³These twigs were evidently much dried out when analyzed, hence the per cents. are corrected about to the average per cent. of water found in the other analyses given in the table, or to 40% more water than they are credited with in the original report.

Table XIV.—THE COMPOSITION OF APPLE TWIGS AND WOOD.

(American Analyses reduced to the basis of dry substance).¹

Analyst or Author.	Number of Varieties.	Dry Substance, %	N. %	P ₂ O ₅ %	K ₂ O %	CaO %	MgO %	Fe ₂ O ₃ %	Total Ash. %
Patrick, '89,-----	4	53.2	1.0759	.169	.2028	1.927	.9614	.0534	3.87
Collier, '91,-----	3 (yg.)	57.22		.1941	.3790				3.4218
Roberts, '95,-----	6 (yg.)	53.56	.5601	.1042	.2561				
Roberts, '95,-----	1 (old)	56.1	.2745	.2916	(.9157) ²	.9713	.9932	.0201	2.6631
Schwitzer, '98,-----	3 (water sprouts)			(.4631)	(.9439) ²	.2.3894	.1265	.0221	(4.8818)
Schwitzer, '98,-----	3 (bearing twigs)		.4433						
Traphagen, '03,-----	9 (yg. twigs)	(93.838) ³	.5738	.3284	.4776	.2.5372	.4776		
Traphagen, '03,-----	9 (older twigs)	(93.74) ³	.9404	.3919	.5038				
Van Slyke, et al., '05,-----	2 (twigs)	47.65	.3956	.3614	.5601				3.3333
Van Slyke, et al., '05,-----	9	50.02	.7654						
Warren & Voorhees, '06,-----	1 (aver. for 10 yrs.)								
Averages, in % of dry substance,-----	50	52.96	.691	.2343	.3965	1.7555	.2397	.0822	3.3200

¹Data of Table XII recalculated by the writer to per cents. of dry substance, except the dry substance column, which is in terms of green weight.²These trees were receiving heavy applications of potash, which probably accounts for the abnormally high results here.³See footnote 3 to Table XIII.

Meaning of Variations Observed in Composition.—In the preceding tables, i. e., those which have been reduced to uniform basis, it will be noted that, while in general there is very good agreement, yet there are some rather marked variations. Some of these are doubtless due to manipulative or experimental errors. It is to eliminate these, in so far as possible, that we have resorted to the method of averages.

But aside from this, some of these variations are undoubtedly connected with actual differences in composition of the parts at the time of analysis. These differences may be partly due to losses with increased maturity or age of the parts. Such losses are very likely to occur, in the case of leaves especially, when permitted to remain on the trees until full maturity before analyzing.¹

But another and an important part of the observed differences in composition is to be connected with evident migrations of mineral constituents from the older parts to the younger, and from various vegetative parts to the fruit. In connection with the former point, in Table XIV for example, if we compare Roberts' composition figures for the old tree with those of Van Slyke for the twigs of similar mature trees, we find a very marked increase in the latter.

In the elements reported, the twigs run from 2 to nearly $3\frac{1}{2}$ times as rich as the average for the whole tree in Roberts' figures, which of course include the twigs and smaller roots. The same general relation appears in the German averages, shown below in Table XVII, for trunk and limbs as compared with fruit wood (Fruchtholz), the latter being about twice as rich as the former.

This relative richness of twigs as compared with wood, indicating a migration of ash constituents from the latter to the former, is also very strikingly shown in the peach. This may be seen in the following table, No. XV, from results reported by Warren and Voorhees.²

Table XV.—RELATIVE COMPOSITION OF OLD AND NEW WOOD IN THE PEACH.

(New Jersey Results.)²

	N. %	P ₂ O ₅ . %	K ₂ O. %	CaO. %
Season's twigs, -----	1.32	.34	.54	1.73
Trunk and branches, -----	.28	.11	.15	.33
Rootlets (under 1 inch in diam.), -----	.82	.27	.31	.61
Larger roots, -----	.43	.09	.25	.34

As shown in this table, the new twigs were from 3 to 5 times as rich as the old wood, with the small roots $1\frac{1}{4}$ to 3 times as rich as the larger ones. In the peach tree examined, the new twigs are reported to have contained about one-fourth of the plant food used in the wood growth of the year.

On the second point,—the migration of mineral elements to the fruit,—we would call attention to an interesting relation existing between size of the fruit crop and composition of leaves. From

¹See article by LeClerc and Breazeale in U. S. Year Book, 1908, pp. 389-402.

²Warren and Voorhees, J. A., New Jersey Experiment Station Report 1906, p. 201.

present evidence, the ash-composition of leaves is much lower on trees with fruit than on those without fruit. A hint of this may be seen in Table X, in comparing Roberts' figures for the two trees. The thirteen-year tree had no fruit in the year in which the leaves were analyzed, while the older tree had apples. Although there are too many other varying factors for a good comparison here, yet it will be observed that the leaves of the tree without fruit averaged nearly twice as rich as those of the tree where fruit was present.

The best analyses that we have discovered bearing on this point are again to be found in connection with the peach, and are reported by Warren and Voorhees. These are shown in Table XVI, which is derived from page 200 of the New Jersey Annual Report for 1906.

Table XVI.—RELATION OF LEAF COMPOSITION TO SIZE OF CROP IN THE PEACH.

(From Results in New Jersey.)

	N. %	P ₂ O ₅ . %	K ₂ O. %
First 4 years (no fruit), ...	4.09	.70	2.12
Five years (with fruit), ...	2.67	.55	1.42
1904, 8th year (no fruit), ...	3.09	.66	1.80

These figures, being averages for several years from the same tree, are doubtless quite reliable. They show that evidently a very considerable transfer of materials takes place from the leaves to the fruit in crop years. The same is true of the ash of apple, plum, and pear leaves, as indicated in the analyses made at the New Jersey Station.

It is probable also that the twigs act similarly to some extent, as storage organs or sources of mineral food supply for the fruit. But apparently no analyses bearing upon this point are available.

German Analyses of Apples.—The average composition of apple fruit and vegetative parts, as determined by many analyses made by leading German chemists, is shown in Table XVII. Only the averages are given in this case. They are derived from analyses made by Dr. Barth, of the Colmar Agricultural Experiment Station; Doctors Steglich and Richter, of the Dresden Station; Dr. Edward Hotter, Graz Station; Dr. Richard Otto, Laboratory at Proskau; Professor Karl Reichelt, Friedberg Laboratory; and König, in *Chemie der menschlichen Nahrungs- und Genussmittel*, I: 823, 826, 828 and 832; and II: 959.

For the other original data and references, the reader is referred to the article by Steglich on *Statik des Obstbaues*, in *Arbeiten der Deutschen Landwirtschafts-Gesellschaft*, No. 132: 1-147, 1907. The number of analyses considered in obtaining the averages for the various parts, and also the analysts making them, are indicated in each case.

The "static values" included are the estimates of Steglich, used in deriving his system of Statics of Fruit Culture, which is discussed more fully later.

Table XVII.—COMPOSITION OF VEGETATIVE ORGANS AND FRUIT OF THE APPLE.

(German Analyses calculated to dry weight basis.)

Plant Part.	No. of Analyses.	Dry Substance. %	N. %	P ₂ O ₅ . %	K ₂ O. %	CaO. %	Total Ash. %
Root wood, -----	4 ²	45.72	.315	.106	.232	.544	2.315
Trunk and limbs, -----	11 ³	50.36	.49	.123	.268	1.277	4.443
Fruit wood, -----	7 ³	53.54	.883	.282	.515	2.729	-----
Branches, -----	-----	(50.36)	(.536)	(.139)	(.233)	(1.422)	-----
Average composition of wood, -----	22	51.54	.563	.1703	.338	1.517	3.381
Static values ⁴ for wood, -----	-----	49.	.47	.13	.29	1.10	-----
Average composition of leaves, -----	7 ⁵	29.21	2.263	.43	1.533	2.612	8.25
Static values ⁴ for leaves, -----	-----	29.	2.3	.45	1.60	3.00	-----
Average composition for fruit, -----	60 ⁶	16.4	.387	.177	1.178	.094	2.153
Static values for fruit, -----	-----	16.5	.40	.200	1.200	.100	-----

1. Table prepared by the writer from data given by Steglich in Statistik des Obstbaues, pp 6874.

2. Analyses made by Dr. Barth, Dr. Steglich, and Dr. Reichelt.

3. Analyses made by Doctors Barth, Steglich, Otto, and Reichelt. 36 determinations made of the water content.

4. Values used by Steglich in deriving his "static system" for estimating manurial requirements upon basis of trunk circumference.

5. Analyses (7) made of mineral constituents by Barth, Steglich, and Richter. Four analyses of total ash by Barth and Steglich, and 3 of dry substance by Richter.

6. 60 analyses of mineral constituents and 24 of total ash by Barth, Hotter, and König. Over 60 determinations of moisture.

Combining the final American averages, obtained in Tables VIII, XI and XIV, with the German averages shown in Table XVII, we obtain the following Table, No. XVIII.

TABLE XVIII.—THE COMPOSITION OF APPLE WOOD, LEAVES, AND FRUIT.

(Calculated to dry substance basis.)

	Plant Part.	Dry Substance. %	N. %	P ₂ O ₅ . %	K ₂ O. %	CaO. %	MgO. %	FeO ₂ . %	Total Ash. %
Average of American and German averages, -----	Wood, --	52.25	.637	.2023	.3672	1.636	.93971	.03221	3.353
Values used in our computations, -----	Wood, --	52.	.62	.20	.36	1.6	.24	.03	3.35
Average of American and German averages, -----	Leaves, --	34.15	2.149	.4451	1.3484	2.467	.75481	.12471	8.69
Values used in our computations, -----	Leaves, --	34.	2.15	.44	1.34	2.45	.75	.125	8.6
Average of American and German averages, -----	Fruit, ---	15.39	.4238	.1093	1.1075	.0843	.08291	.01931	2.036
Values used, -----	Fruit, ---	15.4	.43	.17	1.10	.08	.09	.02	2.035

1. Averages of American analyses only.

Founded as it is upon the large number of analyses of accurate men, whose personal equations are doubtless eliminated by the method of averages, this Table XVIII should come nearer the actual average composition of the parts considered than has been done before. For the same reason, it is probably a closer approximation of the true composition of apple fruit and vegetative parts than we have for any similar woody plant. This is because the reported compositions of such plants are usually based on relatively few analyses, and single analyses, as we have seen, are subject to quite wide variations.

In the values adopted for our later computations, we have tried to be conservative in all cases. Whenever any deviations have been made from the averages they are either reductions or are toward the side of preponderating evidence.

The relatively high plant-food content of the leaves, and the marked differences in relative demand made by the various parts, are quite noteworthy. But this is in harmony with observations on other similar woody plants. It may also be noted that from the work of LeClerc and Breazeale, referred to later,¹ the percentage composition in the ash of leaves, may depend to some extent on the rainfall, and that it is quite possible that the ash requirements might be considerably in excess of the ash actually found in leaves that had been washed frequently by rains.

Annual Weights of Leaves, Wood and Fruits, Produced by Mature Apple Trees.

With the composition of various parts fairly settled, the next stage of our process is to determine the approximate weights of these parts annually produced under satisfactory orchard conditions.

This is readily done in the case of the fruit. For it we have decided upon an annual average of about 14 bushels, or 700 pounds, per tree for the mature orchard. This is less than half the weights we have secured in single years from mature experimental trees, 1,500 to 1,600 or more pounds per tree being not infrequent among the trees of our Experiment 221. Many individual cases are also known with crops much higher than these. On the average, however, a fruit production of 700 pounds per tree, which makes 490 bushels per acre of 35 trees, may be considered a satisfactory return for a good orchard.

When we come to determine the average annual production of wood and leaves, however, our evidence is far less clear. The data which we have are shown in Table XIX.

¹LeClerc and Breazeale, Plant Food Removed from Growing Plants by Rain and Dew. U. S. Department of Agriculture: Year Book, 1908: 389-402

Table XIX.—OBSERVED WEIGHTS OF LEAVES AND WOOD OF APPLES.

(Average weights per tree.)

Author or Observer.	No. of trees.	Age, yr.	Leaves.		Wood and Roots.	
			Green wt., lb.	Dry wt., lb.	Green wt., lb.	Dry wt., lb.
Roberts, ¹ -----	1	13	33.18	17.26	-----	-----
Roberts, ¹ -----	1	"old"	232.	92.51	5251.4 ²	2951.2 ²
Van Slyke et al. ³ -----	2	30	80.52	34.72	(7.035)	(3.685)
Steglich ⁴ (X2), -----	-----	37	99.2	28.79	111.1	54.35
Average per year, -----	-----	-----	111.1	43.32	108.0 ⁵	56.68

¹. Cornell Bulletin 103: 534 and 538-40. 1895.

². These are total weights of wood in one old "Westfield tree, said to be below normal in size.

³. Van Slyke, Taylor and Andrews. Geneva Bul. 265: 209. 1905.

⁴. Statistik des Obstbaues, p. 95. The values are taken for trees with trunk-girth of 119 cm., such as are found in our experiment 221. Steglich's figures are reduced to English units and doubled for reasons indicated later.

⁵. In getting these averages, Roberts' wood weights are divided by 50, on the assumption that they were capable of being produced in about 50 years of mature tree-growth, and the quotients are averaged with Steglich's estimates. Van Slyke's wood weights are excluded in deriving averages, since they are only those of the current season's twigs.

The sources and details of the data shown here are given in the footnotes. In Roberts' figures, the leaf weights of the old tree look rather excessive, but they are fairly well offset by those of the thirteen-year tree, which are evidently low. The wood weight found in the old tree is the total made during its life. Since it is said to have been below normal size, we have assumed that it would have been produced by 50 years of normal mature tree-growth,—doubtless a safe assumption,—as others have considered it "growable" in 45 years.

In Van Slyke's figures, the wood weights given are only those of the twigs of the current season. The new wood of the roots, and the wood of annual increase in thickness throughout the tree are not included.

It will be recalled that in Warren's findings in the peach, the new twigs contained about one-fourth of the total plant food of a year's growth, and were from three to five times richer than the general wood of the tree. On this basis and also on the basis of the other observations on apple growth, it is probable that Van Slyke's twig weights should be multiplied by about 15, in order to give a fairly close approximation to the true annual wood production. It has seemed better, however, in this case, to exclude them in making the final averages.

Steglich's estimates in the original are given in kilograms per centimeter of trunk-girth. In getting his particular estimate for this table, his figures for trees of 119 centimeter trunk-girth, such as those in our Experiment 221, were reduced to English units, and doubled for reasons explained later.

Some corroboration of the average secured in Table XIX is obtainable from studies made on the peach. For example, it appears from the data on page 218 of Geneva (N. Y.) Bulletin 265 that an apple tree takes up about $2\frac{1}{2}$ times as much plant food as a peach. It is also shown in the same bulletin that the composition of the two trees is not materially different. Wood and leaf weights found for the peach, therefore, multiplied by $2\frac{1}{2}$, should give us an approximation of the similar weights for the apple. Such weights are given in Table XX.

Table XX.—OBSERVED WEIGHTS AND ESTIMATES OF LEAVES AND WOOD IN THE PEACH.

(Average weights per tree.)

Author or Observer.	No. of trees.	Age, yr.	Leaves.		Wood and Roots	
			Green wt., lb.	Dry wt., lb.	Green wt., lb.	Dry wt., lb.
Warren and Voorhees ¹ , --	1	10	170.5	-----	316.2	-----
Warren and Voorhees ¹ , --	-----	-----	21.31	-----	39.525	-----
Average per year ² (8 yr.),	-----	-----	45.75	16.93	12.833 ³	-----
Van Slyke ³ , -----	3	7 & 9	-----	-----	-----	5.47
Rough estimate for peach,	-----	-----	40+	-----	50+	-----
Derived estimate for apple (peach X $2\frac{1}{2}$) ⁴ , -----	-----	-----	100+	-----	125+	-----

¹. N. J. Station Annual Report 1906: 192-204, Table V. The weights given are the totals for ten years.

². The 10 years' growth is equivalent to not over 8 years of mature tree growth, since the first years' growth produced only about 1/40 of the amounts averaged in the last six years, with the second year producing $\frac{1}{3}$, the third, $\frac{2}{3}$, and the fourth year fully these amounts.

³. Geneva Bulletin 265: 211. Weights averaged by the writer.

⁴. Reason for multiplying by $2\frac{1}{2}$ is explained above.

These weights and estimates are evidently only approximate, so far as conditions in any given orchard are concerned. In the case of the New Jersey results, for example, we have assumed that the total weight found could have been made in 8 years of mature tree-growth. It is probable, however, that 6 or 7 years would have been ample, since the tree studied evidently did not do as well as the average trees in their orchard, its fruiting being less than half that of the latter. This shorter period would naturally increase the yearly averages calculated from their results.

Van Slyke's leaf weights are evidently satisfactory, being the average from three trees during one season. His wood weights, however, are again unsatisfactory, because again they represent only the current season's twigs. They therefore probably do not show more than one-fifth of the actual annual wood-production, for reasons stated above.

On this assumption, together with the actual weights shown in the New Jersey results which are evidently low, the estimate of 50 pounds of wood produced annually by a mature peach tree is probably at least not excessive.

The derived estimates for apple trees correspond very well with those of Table XIX. On the basis of both tables an estimate of the annual production by mature apple trees of 100 pounds each of wood and green leaves seems to us to be approximately correct, and at least not to be excessive. These are the weights that we have used later in our computations of annual draft on the soil.

The Annual Plant-Food Requirements of Mature Apple Trees.

Various attempts to answer this question have been made in the past. Of these, by far the most elaborate and comprehensive is that of Doctor Steglich, of the Dresden Station in Germany, to which we have already referred. In an article on Statics of Fruit Culture,¹ published in 1907, he has developed a very complete system for estimating the annual weight increase and manurial requirements of individual trees. In his system, the trunk circumference (*Stammumfang*) is used as the determining factor. The plan is developed for the pear, cherry and plum, as well as for the apple, and it is based on a large amount of tabular data.

The data show: (1) The weight relations of the roots, trunk, branches and leaves; (2) The annual increase in growth; (3) the annual leaf and fruit production and their relation to the trunk circumference; and (4) the chemical composition of the vegetative organs and fruit. A large table is given, showing for the wood, leaves and fruit, of the fruits named above, their estimated content of green and dry substance and their mineral requirements, for each centimeter of trunk circumference from 15 cm. up to 150 cm. in most cases.

To test this system of Steglich's, we have applied it to the trees of certain of our experiments whose average trunk circumference was known. The results are given in Tables XXI and XXII.

¹Steglich. Statik des Obstbaues. Arbeiten der Deutschen Landwirtschafts-Gesellschaft, No. 132: 1-147. 1907.

Table XVI.—ANNUAL REQUIREMENTS FOR PLANT FOOD OF APPLES, PER TREE.

(Steglich's estimates¹ applied to certain of our experimental trees.)

Experiment Number.	Variety.	Age of Trees, Yr.	Average Trunk Circum. cm.	Green Wt. Kg.	Dry Substance. g.	N. g.	P ₂ O ₅ . g.	K ₂ O. g.	CaO. g.
216,	York Imperial,	10	39	49	11.64	85.73	25.19	109.83	108.23
216,	Jonathan,	10	43	55.64	13.12	96.5	82.45	124.82	120.77
338,	Baldwin,	22	97	145.21	32.93	238.54	71.92	321.25	286.18
221,	Baldwin & Northern Spy,	37	119	181.7	40.99	296.68	89.07	405.02	333.86

¹. Statistik des Obstbaues, pp. 85-95. This table gives the annual requirements per tree in grams, as shown in Steglich's system. The nearest integral equivalents in centimeters for the average trunk-girths of our trees, as found in 1909 and 1910, are used in obtaining the corresponding values.

Table XVII.—ANNUAL REQUIREMENTS OF APPLE TREES PER ACRE.

(Date of Table XXI recalculated into English units.)¹

Experiment Number.	Variety.	Age of Tree, Yr.	Average Trunk Circum. in.	Green Wt. lb.	Dry Substance. lb.	N. lb.	P ₂ O ₅ . lb.	K ₂ O. lb.	CaO. lb.
216,	York Imperial,	10	15.33	3780.8	898.1	6.61	1.94	8.47	8.35
216,	Jonathan,	10	16.83	4293.2	1234.5	7.44	2.19	9.63	9.32
338,	Baldwin,	22	28.10	11204.5	2540.9	18.40	5.55	25.02	22.08
221,	Baldwin & Northern Spy,	37	47.27	14620.0	3162.8	22.80	6.92	31.3	27.30

¹. These calculations are made to an acre of 35 trees, the number used in other estimates considered later. The number actually planted is 48 per acre in all cases except the last, which has 27. (The multiplying factor used in making the conversions was: kg N 77.1605 = pounds per acre, of 35 trees.

Before passing judgment upon the accuracy of these estimates, we will look at those of another eminent German chemist, Doctor Barth, of the Experiment Station at Colmar, Germany. Barth's calculations¹ of the requirements of various fruit trees, including apple, cherry, peach and pear, were made on the basis of some 90 original analyses of vegetative parts, supplemented by collated analyses of fruits, and by researches on the growth of wood, leaf and fruit. In his calculations, the individual tree requirements are based upon the area of soil covered by the tops. His final estimates for the fruits named are given in Table XXIII.

Table XXIII.—BARTH'S ESTIMATE OF THE FERTILIZER REQUIREMENTS OF FRUITS.

(Stated in grams per square meter of area covered by tops.)

	N gm.	P ₂ O ₅ . gm.	K ₂ O. gm.	CaO. gm.
Apple, -----	7.1	1.5	7.30	9.80
Peach, -----	7.	2.3	10.63	8.42
Pear, -----	7.5	2.1	10.90	6.70
Cherry, -----	11.9	3.1	15.95	21.05

The general formula which he derived from these figures is: N, 10 gm.; P₂O₅, 5 gm.; K₂O, 15 gm.; and lime, 20 gm.; per square meter of area covered by the tops.² Disregarding this general formula, however, and applying his figures for the apple to the trees of our Experiment 221, which had an average top diameter of about 9 meters in 1910, we obtain the results shown in Table XXIV.

Table XXIV.—BARTH'S ESTIMATE OF THE ANNUAL REQUIREMENTS OF APPLES.

(Applied to our experiment 221, and to acres partly or wholly covered.)

Amounts.	Age of Trees, Yr.	Area Covered by Tops.	N.	P ₂ O ₅ .	K ₂ O.	CaO.
Per tree, -----	37	63.6 sq. meters, --	451.68 gm.	95.426 gm.	464.4 gm.	623.45 gm.
Per acre (35 trees),	37	-----	34.85 lb.	7.36 lb.	35.82 lb.	48.1 lb.
Per acre, -----	-----	100% of acre, ---	63.34 lb.	13.38 lb.	65.13 lb.	87.44 lb.
Per acre, trees in squares, limbs touching.	-----	78.2% of acre ³ , --	49.53 lb.	10.46 lb.	50.93 lb.	68.37 lb.

¹ Barth. A Progress Report on Investigations of Fertilizer requirements of Fruit Trees. Gartenflora, 48, No. 5: 125-126, 1899.

² The large amount of K₂O was included to provide for the cherry; and the P₂O₅ content was increased beyond the yearly requirement because of its slow availability. Among other interesting things, his analyses showed that the ash of the pits of cherries and plums is largely P₂O₅, and that N is present in considerably greater quantities than the ash.

³ This is the relative amount of an acre covered by trees exactly circular, just touching at the tips of the branches, and set in squares.

The first line of this table is derived from the data of Table XXIII as stated above. The others have been calculated from it, reducing the estimates from grams per tree, as shown in the first line, to pounds per acre, for the different ways indicated of estimating an acre. As compared with Steglich's estimates for the same trees,—those of Experiment 221,—Barth's range distinctly higher. If the comparison is made between Steglich's estimates and those of Barth, as shown in the last line,—which is really a fair way of applying Barth's formula when the distribution of roots is considered,—it will be seen that the latter's estimates average about twice as high as Steglich's.

By further comparison with other estimates, such as those shown in our next two tables, it appears fairly certain that those of Steglich should in general be doubled, at least so far as the annual draft of plant food is concerned. This of course does not mean that Steglich's is not valuable; it merely shows how to use it. As a *basis* for estimating the particular quantities *required* for a given tree, his system is undoubtedly the best. It is even unrivalled, except by that of Barth.¹

There are some minor imperfections in his work, however, which have led to the adoption of the low values indicated, and from all the evidence it appears that in applying his system to apples at least, the values should be approximately doubled. This we have done in certain of his estimates for insertion into Table XXV.

Table XXV.—ANNUAL PLANT FOOD DRAFT OF APPLES, PER ACRE.

(Estimates by American and German Authors.)

Author.	No. of Trees Studied.	N. lb.	P ₂ O ₅ . lb.	K ₂ O. lb.	CaO. lb.	MgO. lb.
Van Slyke ² , -----	2	51.5	14.	55.	57.	23
Roberts ³ , -----	2	62.2	18.3	59.4	-----	-----
Barth ⁴ , -----	-----	49.5	10.5	51.	68.	-----
Steglich ⁵ (X2), -----	-----	45.8	13.8	62.6	54.6	-----
Average, -----	-----	53.	14.15	64.5	59.9—	23

The estimate for Roberts in this table is obtained by dividing by 20 the data in his Table 19; by dividing by 50 the plant-food totals obtained from his tables 12 to 15; and by adding to these quotients the weights of plant-food constituents contained in a 400-bushel crop of apples of the composition given in his Table 4. In Roberts' own

¹So far as actual requirements go, Steglich's estimates may still be a fairly close approximation of the true minimum plant-food values, since it is well known that a plant regularly takes up more minerals than it really needs if the excess is available. On the other hand, analyses of mature structures may show less mineral content than is actually required, on account of the apparent losses in such structures as a result of washing by rain and dew.

²Van Slyke, Taylor, and Andrews. N. Y. Geneva Bul. 265: 220. 1905.

³Roberts. Cornell Bul. 103: 538-40. 1895. Derived from data in his Tables 12, 13, 14, 15, and 19.

⁴Gartenflora, 48: 125-126. 1899. The estimate here is that given in the last line of our Table XXIV.

⁵This estimate is that shown in the last line of our Table XXII, with the values doubled to make it more nearly comparable with the others.

estimates of annual draft, a 525 bushel crop is used. The estimates of the others are obtained as indicated in the footnotes.

As finally arranged, the estimates of Table XXV show some rather marked variations so far as individual elements are concerned. Most of these are at least partially explainable, however, and the final average should be fairly reliable.

Our own calculations and estimates of the annual draft of apples are given in Table XXVI.

Table XXVI—ANNUAL PLANT-FOOD DRAFT OF MATURE APPLES, PER TREE AND PER ACRE.

(Computed by the writer from foregoing data.)

Estimated Per Tree.	Green Weights ¹ .	Dry Substance, lb.	N. lb.	P ₂ O ₅ . lb.	K ₂ O. lb.	CaO. lb.	MgO. lb.	Fe ₂ O ₃ . lb.	Total Ash. lb.
Wood, -----	100 lb.	52.	.3224	.1040	.1872	.8320	.1348	.0156	1.742
Leaves, -----	100 lb.	34.	.7310	.1496	.4576	.8432	.2550	.0495	2.024
Fruit, -----	700 lb.	107.8	.4635	.1332	1.1853	.0802	.0070	.0216	2.195
Total per tree, -----	900 lb.	193.8	1.5169	.4368	1.8286	1.7614	.4768	.0797	6.861
Total per A. (35 trees), -----	31,500 lb.	6783.	52.09	15.29—	64.00	61.65	16.69	2.79—	240.

¹. These green-weight estimates are based upon Tables XIX and XX. For good orchard conditions, they should be about correct on the average, and at least not excessive. With the aid of Table XVIII, however, the annual draft can be computed for any other weights that may be desired.

The bases for computing this table are derived especially from the data in our Tables XVIII, XIX, and XX, and the discussion following. Our composition figures, derived as they are from the mass of analytic data underlying Table XVIII, are believed to be quite reliable. There may still be some question as to the accuracy of our estimates of the annual production of green weights, given in Table XXVI. But they also are based upon the best evidence at present available; and, all things considered, we believe that the present table is a very close approximation of the true average annual draft of mature apple trees upon the plant food of the soil. The striking agreement between our final figures and the average in Table XXV is also noteworthy, and affords further evidence of their accuracy.

The relative drain exerted by wheat as compared with apples is shown in Table XXVII.

Table XXVII.—COMPARATIVE DRAFT OF APPLES AND WHEAT, PER ACRE.

	Estimated	Annual Weights. lb.	Dry Substance. lb.	N. lb.	P ₂ O ₅ . lb.	K ₂ O. lb.	CaO. lb.	MgO. lb.	Total Ash. lb.
Wheat ¹ .		1500	1342.5	30.0	10.00	9.8			
Wheat ¹ .	Grain, --- Straw, ---	2700	2440.8	13.7	5.8	17.	.84 7.18	3.00 3.13	
Totals for wheat,		4200	3783.3	43.7	15.8	26.8	8.02	6.13	
Apples ² .		3500	1820	11.28	3.64	6.55	29.12	4.37	60.9
Apples ² .	Wood, --- Leaves, ---	3500	1190	25.59	5.24	13.95	29.51	8.92	102.3
Apples ² .	Fruit, ---	24500	3773	16.22	6.41	41.50	3.00	3.39	70.8
Totals for apples,		31500	6783	53.09	15.29	64.00	61.63	16.68	240.

¹. A 25-bushel crop of wheat and 1 1/3 tons of straw per acre are used here. The computations following are based on composition figures given in Henry's Feeds and Feeding 1910, pp. 532 and 536; Ohio Bul. 221: 2, 1910; and Wolff's Aschen-Analysen, 1899. The composition values adopted for wheat were as follows: Grain—2.0 per cent. N; .67 per cent. P₂O₅; .63 per cent. K₂O; .63 per cent. CaO and .2 per cent. MgO; straw and chaff— .51 per cent. N; .215 per cent. P₂O₅; .63 per cent. K₂O; .366 per cent. CaO and .116 per cent. MgO.

². Computed from the figures obtained in our Table XXVI.

In this table, we have compared a 25-bushel crop of wheat, which is rather above the average, with an apple production that has been shown to be somewhat below it for good orchard conditions. In spite of this, however, it will be observed that the total draft of the apples is greater in every case but one. These figures can hardly be doubted. If the amounts of fruit and wood there indicated are to be produced,—and these amounts are evidently not greater than every good orchardist strives for,—the corresponding amounts of plant food must be forthcoming. The parts have the composition indicated; plant food can not be created, nor can it be drawn indefinitely from the soil without some restoration. If it is not furnished, the production evidently must finally be curtailed.

The wonder, therefore, is not that apples should eventually need fertilization but rather that they can be grown for so long in some cases without it. Especially is this true when no one would think of attempting the same thing with many consecutive crops of wheat,—an actually less exhaustive crop.

Part of the explanation of this is to be found in Table XXVII. Assuming for the present that most of the plant food of the leaves is returned to the soil, which may or may not be true,¹ as is the case with the straw, it will be noted that there is a marked difference between the fruit and the grain in the *distribution of their demand* for the various food elements. The demand of the apple is much more *natural*, i. e., it corresponds much more closely with the relative supply of these materials in the soil. The wheat grain, on the other hand, draws most heavily on nitrogen and phosphorus, which are relatively scarce in most soils.

But even these elements are demanded sufficiently by the apple, especially when the wood and leaves are also considered, to make them distinctly important items. It would therefore appear that in addition to the naturalness of the mineral demand, other factors must be operative in enabling trees to go for considerable periods without apparent need of outside fertilization. The most important of these is undoubtedly to be found in the long season of root activity in apples.² This naturally makes the mineral demand less acute during any given period, and thus enables the natural processes of solution going on in the soil to more nearly meet requirements at all times. The carbon dioxide, developed in the decay of humus or of green manuring covercrops, is also doubtless an important aid in enabling these natural processes of solution to keep pace with demands.

In apples, therefore, the naturalness of the demand, the return of most of the plant food used in the leaves, and the long season of root-activity with its accompanying reduction in urgency of demand at any given time,—all these influences combine in enabling trees to maintain themselves over considerable periods without need of extra fertilization.

¹As shown in the next section on mineral functions, much of the plant food of leaves is washed out, as maturity is approached and passed, and thus it may be returned to the soil to a considerable extent even if the leaves are blown away fairly soon after falling.

²As observed by Goff (Wis. Rpts. 1898: 220-228; and 1900: 291-294) and Crane (Wis. Rpt. 1900: 306-8), the roots of apples and most other woody plants usually start growth in the spring before stem-growth begins, and continue their growth much later. Thus red currant roots on March 31, 1898, were found to have made a new growth of as much as 3 inches, while the buds were but little swollen; and in 1900, the roots of cherry, plum, pear and apple were found to be still growing on October 6, although no increase in twig-length had occurred later than July 1st, a difference of over three months.

Granting that this may often be true for considerable periods, yet enough has been presented above to show that apples really are by no means an inexhaustive crop, and that unless adequate returns are made, plant food in the long run should apparently inevitably become a limiting factor in any vigorous and productive orchard.

The Physiological Functions and Characteristic Effects of the Mineral Nutrients.

In the pages above, we have seen something of the amounts of mineral elements that are contained in the various parts of the apple plant. It remains to be shown approximately what are the generally accepted functions and characteristic effects in plants of the more important of these minerals and of nitrogen. This is desirable, as indicated earlier, partly as an aid in the diagnosis of any given case, and partly to assist in the accurate observation and interpretation of results in any given set of fertilization experiments, whether they be upon apples or wheat.

At the outset, however, it must not be assumed that the exact functions of the various mineral elements are by any means fully known, either for plants or animals. Such knowledge is very difficult to get. This is due primarily to the fact that owing to the intimate correlation existing between different functions, the common method of determining values¹ frequently disturbs or impedes the whole metabolic process, and thus often results in many changes that are not to be credited directly to the particular element omitted. The result is that in no case do we know the entire series of processes participated in by any element from the time of its absorption to its rejection by the plant.

In plants, there are uniformly found some 15 chemical elements, but not all are essential. Those constantly found are the organic elements,—carbon, hydrogen, oxygen and nitrogen;—and the so-called minerals,—sulphur, phosphorus, potassium, magnesium, iron, chlorine, calcium, aluminum, sodium, manganese, and silicon. Of these, the last five have not been shown to be essential, although only the lower algae and fungi are known to be able to do without calcium. Hence, in the case of the higher plants, its value as a direct plant food seems to us as worthy of consideration as that of nitrogen or any of the other elements usually considered as physiologically active.

Under normal agricultural conditions, however, the elements most likely to be lacking, or to be below their optimum, are nitrogen, phosphorus, potassium, calcium and possibly magnesium. Our discussion is, therefore, confined to them and to iron, since the latter has been of some special interest to fruit growers.

Nitrogen.—This element, with sulphur and phosphorus, serves chiefly in the formation of protein and protoplasm. It occurs, therefore, largely in the living areas, e. g., the cambium layers, leaf mesophyll and growing tips, or in seeds² and other food-storage organs. Like phosphorus, it migrates very strongly from the older, more mature, or dying tissues of plants to the living portions, and toward the heads or upper portions. Like potash and soda also, the assim-

¹This is by the absence or continued severe restriction of the particular element whose function is being studied.

²Note Barth's findings in pits of stone fruits, under our Table XXIII.

ilated nitrogen is apparently subject to very considerable losses as maturity is reached and passed, due to migration and the action of rain and dew.¹

In general, the effect of nitrogen applications is to produce a strong vegetative growth, and to greatly retard maturity and ripening in most plants. Cabbage, which is merely a bud and hence a vegetative structure, constitutes an exception, it being hastened rather than retarded in maturity; and the same is apparently true, with early applications only, in the case of some other vegetables such as tomatoes. With apples the retarding effect is usually very marked.

Where nitrate applications have been shown to increase the nitrogen content of the crop, it has apparently been accomplished more by delaying maturity than by actual addition of N. This is brought out especially in the case of mangels, and also with wheat and barley, in the Rothamsted Experiments. These experiments also showed increased susceptibility to rusts and leaf spot in mangels, but in our own experiments with apples, in which the foliage had been attacked by the so-called "frog-eye" leaf spot (*Sphaeropsis*), these results were reversed, the nitrate-fertilized trees being much the more resistant.²

Phosphorus.—This element is an essential constituent of nucleoproteins and renders their formation possible. It is therefore necessary for cell divisions and for all new growth, and in its absence these processes stop, as shown in Loew's experiments with algae. Its absence also results in an accumulation of fats and albumin; and its presence is shown by Loew to be necessary for the formation of lecithin and chlorophyll.³

As might be expected on account of the demand for it in the new growth, there is an enormous migration from the older portions to the younger, and especially from the straw to the seeds of the grains and fruits during maturity. As with most other minerals, there may be considerable loss of assimilated P_2O_5 , as a result of rains and dew, during maturity and the later stages of plant growth.⁴

An interesting side light appears in the fact that the protein content of seeds and the yield of grain is said to be markedly increased by increased phosphorus supply.⁵

In the Rothamsted work, the ripening process was exceedingly forwarded by phosphorus, giving a difference of 10 days in the case of the barley. It is, therefore, held to be a corrective for the retarding influence of nitrogen, and its effects are notably better in a wet season. This has not been clearly corroborated as yet in our apple experiments.

In the English work also, P_2O_5 was found to promote root development very markedly, but not exactly in proportion to its supply, as

¹See article of Le Clerc and Breazeale on "Plant Food Removed from Growing Plants by Rain or Dew." U. S. D. A., Year Book, 1908: pp. 380-402.

²See Penn. Sta. Bul. 91, figures 2 and 3; and Bul. 100: 25, 1910.

³U. S. Bureau of Plant Industry, Bul. 45: 16-19. Lecithin is a semi-soluble substance regularly accompanying fatty matter, but physiologically superior to it because of its partial solubility. It thus probably serves for respiration, being the form into which fat must be changed to become combustible in the protoplasm.

⁴In LeClerc and Breazeale's work the losses with wheat were as follows: N, 7%; P_2O_5 , 33%; K_2O , 54%; soda, 41%; lime, 34%; magnesia, 46%; and chlorin, 60%. In the work of Wilfarth, Römer and Wimmer, losses were found as follows: N, 23%; P_2O_5 , 3%; K_2O , 38%; and soda, 47%. U. S. D. A. Year Book, 1908, pp. 395-97.

⁵U. S. Bureau of Plant Industry. Bul. 45: 16-19.

there is an unknown factor cutting across results. Tillering and therefore bud formation in stem and roots are greatly promoted by it.¹

Potassium.—Some potassium salts are necessary for every living cell. They seem to be connected especially with starch formation. In their absence the polymerization of formaldehyde (CH_2O), the first organic compound in plants, into $\text{C}_6\text{H}_{12}\text{O}_6$ etc. apparently does not go on so readily. Potash also seems to be connected with protein formation, which may be a similar process, and with protein accumulations.² Those parts in which carbohydrates are transported are also reported to be relatively rich in potash,³ though this does not prove any vital connection.

Under normal conditions, potash is likely to be of special importance as a fertilizer where carbohydrates are the important parts of the crop, e. g. sugar beets, mangels, and probably fruits. The latter point is indicated by the composition of apples as shown in Table XVIII, but it has not yet been clearly shown in our field experiments, probably because potash has not proved to be clearly deficient as yet on the check plots.

In the Rothamsted experiments, when N and P are diminished, the yield of grain is reduced but the individual kernels are of normal size. When potash is lacking, however, the kernels are also under-size, thus indicating that assimilation has been checked in its absence. Also there are many blind florets and weak seeds in wheat and barley; and with grass there are many reddish or purplish leaves with dying tips on the potash-starved plots. In the English experiments, potash reduced rust-attacks on beets, and tended to reduce lodging in grain. It also appears to assist plants in resisting drought, as indicated in Atkinson's work on cotton leaf blight.⁴ This is possibly due to its reputed value in increasing the osmotic power of the cell sap.

There is a difference of opinion as to its relation to maturity, some maintaining that it hastens maturity and others that its usual effect is to prolong growth. Those holding the latter view consider it especially effective on the lighter soils and in dry seasons. The plant habit of closing up growth on the occurrence of malnutrition of any sort, probably accounts for some of the divergence in views. No marked effect either way has yet appeared in our apple experiments, though perhaps the tendency has been to hasten maturity.

It is worthy of note that where nitrate of soda has been used as a nitrogen carrier, in the Rothamsted work, no sign of potash failure has been observed in 12 years. This is taken to indicate that sodium liberates potash in the soil.

While potash shows relatively little migratory tendencies in cereals at any rate, yet it is subject to very marked losses with increasing maturity of the plants, as shown in the discussion of phosphorus above.

Magnesium.—This element is required by all plants. Its distribution and importance in them is apparently rather similar to potas-

¹Lectures by A. D. Hall, Director of the Rothamsted Station in England, in 1908 at the Graduate School of Agriculture, Ithaca, N. Y. The other references here to Rothamsted work are based on these same lectures.

²This is indicated for example in the correlation of higher potash and higher protein content in seeds of legumes as compared with those of cereals.

³Loew, U. S. Bureau of Plant Industry 45: 28-30.

⁴Alabama Station Bulletin 36. Also see Duggar's Plant Physiology, p. 174, 1911.

sium. As pointed out by Loew, however, it can perform its proper function only in the presence of calcium salts,¹ since, with the exception of a very few plants, it is strongly toxic otherwise. Loew considers it especially important in the formation of seeds and of proteins although it is required in the development of all plant parts.

Its action is indirect, that is, it does not enter directly into the composition of plant parts or tissues, but apparently serves rather as a carrier of the phosphorus needed in their formation. According to Loew, this view is probable because of the relatively easy decomposition of the secondary magnesium phosphate into territory and free phosphoric acid, a dissociation which would naturally immediately precede assimilation. At any rate, magnesia is found always to increase when rapid development is taking place, and comparatively little of it will serve for extended physiological operations, which rather corroborates the view just stated. A connection between magnesia and phosphorus is also shown in the work of Reed on *Spirogyra*.²

As compared with lime, the magnesium content of leaves and wood is always noticeably lower, while the reverse is markedly true of the content of seeds,³ and also of fruits as indicated for the apple in Table XVIII.

Magnesium also migrates strongly to the growing parts, in general "following the proteids, like the phosphates." Its exact relation to fruit development is not known, though the results in the Massachusetts experiment⁴ suggest a possible value. Its relatively high content in fruits, as well as its apparent relation to phosphatic compounds, is also suggestive. It seems that nothing is known concerning its relation to the hastening or retarding of maturity in crops.

Calcium.—The use of lime in agricultural practice is very old. In many soils it is an important factor; and with the large demand of most plants for it, its need is often felt very early. The part that it may play in the nutrition of plants is variable. In some soils, its action is physiological, while in others it merely modifies environment.

Since fungi and certain algae do not require calcium, and since it may be largely or entirely absent from primary meristem and from young plant organs generally, it seems that lime is "not essential for vital activity in general but only for certain special processes."⁵ In the higher plants, however, it has apparently acquired such importance for these special functions, that its absence may indirectly affect one or all of the vital activities, and thus obstruct metabolism generally.

The special function that has been most clearly associated with calcium is concerned with the solution and transfer of starch, as contrasted with the starch-building role of potash. The irregularities in starch-transfer, in the absence of lime-salts, were first observed by

¹U. S. Bureau of Plant Industry. Bul. 45:55-67. 1903.

²Reed, H. S. The Value of Certain Nutritive Elements to the Plant Cell. Ann. of Bot. 21: 501-543. 1907.

³U. S. Bureau of Plant Industry. Bul. 45. See pp. 35-37 on relative distribution of lime and magnesia in plants. The preponderance of Ca over Mg. in soils need not be especially great, though more appears to be required by crops having very abundant foliage. The experiments of May (1900) in Washington and of Aso and Furuta (1901) in Tokyo, indicate that cereals thrive best when the lime content of the soil only slightly exceeds that of magnesia, while cabbage needs twice as much lime, and buckwheat three times as much as magnesia.

⁴See results in plots 4 and 5 of our Table XXXIV.

⁵Peffer. The Physiology of Plants, I: 433.

Boehm. In his observations, the starch accumulated in the pith and lower part of the stem and resulted in the death of the plants, the injury appearing first in the upper parts. The difficulty disappeared when lime salts were added. The function of lime in acid neutralization in plants is now considered less essential than formerly, since the resulting calcium oxalates are found to be absent in many plants. Boehm and Molisch also hold that lime is important in the laying down of the cell wall, particularly the middle lamella.¹ If true, this may have some application in fruit-production, since the mealiness of apples appears to be due to the breaking down of this lamella, with the consequent separation of the cells without rupture. The relation of lime-salts to this has apparently not been studied.

In plants, lime accumulates especially in the leaves, as shown in Table XVIII, and to a less extent in the wood. Etiolated, diseased or albino leaves, contain much less lime than healthy green leaves,² the reduction sometimes being to less than half. And young pine trees grown in the absence of calcium produced new leaves only to half their normal size.

It is therefore likely to be valuable in the fertilization of vegetative or leafy crops, such as cabbage, lettuce, and turnips.

In its ecologic or soil-modifying capacity, lime may function as follows: (1) *Corrects acidity*. Most plants prefer slightly alkaline soils, though there are some important exceptions, which apparently include the cowpea, watermelon, grape, and Japan clover. The exact preference of the apple is not known. (2) *Liberates other nutrients*. This "whip" action has sometimes been considered the only function of lime. The liberation should not become too fast, however, or losses may occur by leaching. (3) *Tends to preserve nitrogen*. (4) *Flocculates heavy soils*. (5) *Possesses some fungicidal and insecticidal value*. Thus it is often effective against snails, and reduces or prevents club-root of cabbage, but it favors potato scab. (6) *It corrects the toxic action of magnesium, and also of many other bases, when they become present in injurious amounts*. This function is discussed later, after the discussion of iron.

Like magnesia, the relation of lime applications to maturity in plants is apparently not definitely known, as is also the case with their relation to the fertilization of orchard fruits. Our experiments thus far have been clearly favorable in only half the cases, as indicated later. The total annual draft of lime is evidently high, as shown in Tables XXVI and XXVII. But very little of this is in the fruit, most of it being in the leaves. They doubtless return much of their lime content to the soil, even though soon blown away, owing to the large losses that occur on maturity, as shown in connection with our discussion of phosphorus above.

Iron. Very little is known of the part that iron plays in plant metabolism. It is required, however, in small amounts by all plants. It was formerly thought to be a constituent of chlorophyll, but this was shown by Molisch³ not to be true. Its presence is still considered one of the indispensables for the formation of chlorophyll, however, its action apparently being one of conditioning the nature of protoplasmic activity. A small portion of the iron in plants also is appar-

¹See U. S. Bureau of Plant Industry, Bul. 45: 41. 1903.

²See U. S. Bur. of Plant Industry, Bul. 45: 38-29, 1903.

³Molisch. Die Pflanzen in ihren Beziehungen zum Eisen, p. 81, 1892.

ently held in the form of organic compounds, possibly entering into the structure of the chloroplastids.¹

As a fertilizer, Bracci² has reported that an application of one part FeSO_4 with twenty parts of cilt to wheat and oat soil, resulted in increased yields of straw and grain, and earlier ripening by several days. Ville³ also reports that a spray of 2 per cent, solution of FeSO_4 upon young apples and pears both hastened the ripening and enlarged the fruits. To the writer this seems rather fanciful, though a serious attempt has been made to explain it on the ground of stimulation of the protoplasm and increased production of chloroplasts in the epidermis.⁴

Considerable discussion and some experimenting has been done among horticulturists on the value of iron applications to the soil in increasing color of fruit, especially of apples. This point is discussed later, on pages 504-505, but it is sufficient to say here that the present evidence is not favorable. This may be because it has not been deficient in the soils tested. The amount of iron in the annual draft of apple trees is worthy of note, as shown in Tables XXVI and XXVII. But it is probably always available in required amounts in any agricultural soil, so that additional applications could scarcely be expected to have any marked influence, at least not directly.

The Toxic Action of Certain Bases and its Neutralization.

In the discussion of calcium above, it will be observed that the sixth ecologic function given for lime is to correct the toxic action of magnesium, and also of other bases, when they become present in injurious amounts. This may frequently be a very important function of lime and it opens up a question that in our opinion has not received the attention it deserves in crop fertilization in general.

This is the question of toxicity of the salts of various bases, especially those of the heavy metals, when present alone in solution, or when distinctly predominating in solutions otherwise weak. This question is coupled with the related fact that their observed toxicity may often be reduced or entirely neutralized by the addition of other bases.

This general relation was first discovered between magnesium and calcium by Loew about 1883, but it has since been extended to salts of various bases or metals, such as sodium, potassium, strontium, barium, iron, manganese, nickel, cobalt, silver, mercury and the NH_4 -radical in ammonium compounds. Their toxic action is shown to exist, above certain concentrations, often in very marked degree, and the neutralizing power of other bases, especially lime, is regularly shown to follow their addition.⁵ The strong toxic action of

¹Pfeffer. Physiology of Plants. I: 426.

²Bot. Jahresber. p. 43. 1883.

³Bot. Jahresber. p. 43. 1883.

⁴U. S. Bureau of Plant Industry, Bul. 45; p. 22. 1903.

⁵Important references on this matter are as follows: Loew, Oscar, U. S. Bureau of Plant Industry, Bul. 45. 1903. Kearney and Harter. Bureau of Plant Industry, Bul. 22. 1902. Kearney and Cameron, U. S. Dept. Agriculture Report 71. 1902. Osterhout, W. J. II. Bot. Gaz. 42: 127-134. 1906; 44: 259-272. 1907. Hansten. Jahrb. f. Wiss. Bot. 47: 289-377. 1910.

McCool, M. M., Thesis at Cornell University. 1911.

Also see Duggar's Plant Physiology, Chap. XVIII. 1911. (This book has appeared since the above discussion was written. Its Chapters VII and VIII also discuss mineral nutrients and their special roles.)

copper salts in solution also has long been known and utilized in spray materials and as an algicide. The neutralizing action of lime additions in these cases also is significant and may be similar to its action in nutrient solutions.

The direct bearing of this upon certain results of our orchard experiments is given later, on pages 461 to 465.

RESULTS FROM THE PENNSYLVANIA ORCHARD FERTILIZER EXPERIMENTS.

A summary of the results on yield, color, size and growth for the second, third, and fourth years of our fertilizer experiments is given in Tables XXVIII to XXXI. Each of these tables gives the combined results from three experiments, the location and details of which are given in Table IV and its following discussion. From the latter table it will be observed that the first three experiments,—215, 216 and 220,—contain 480 trees ranging from 11 to 22 years of age; and the other three considered here,—336, 338 and 339,—contain 320 trees in their fertilizer portions, ranging from 8 to 22 years of age.¹ The total amount of fruit involved in the present tables,—XXVIII and XXIX,—is 222,568 pounds, or something over 4,450 bushels. This, in connection with the number of varieties and soil types involved, makes the physical basis of these tables fairly satisfactory.

Table XXVIII.—INFLUENCE OF FERTILIZERS ON YIELD AND GROWTH IN APPLES.

(Summary of Experiments, 215, 216, 220.)

Plot.	Treatment.	Yields, 1908-10, lb.	Benefit yield, 1908-10, %	Yields, 1910, lb.	Benefit yield, 1910, %	Aver. increase per tree in trunk girth, 1907-9, in.	Benefit growth, 1907-9, %.
1.	Check, -----	10,667		6,024		3.29—	
2.	N. P., -----	15,352	76	8,465	74.3	3.54	8.9
3.	N. K., -----	11,971	76.6	6,318	71.35	3.63	19.1
4.	Check, -----	4,832		2,519		3.18	
5.	P. K., -----	8,764	83.4	5,177	102.	3.34	3.8
6.	P-K ₂ SO ₄ , -----	6,585	39.8	3,812	46.2	3.43	5.1
7.	Check, -----	4,648		2,653		3.19	
8.	N. P. K., -----	9,605	71.9	5,768	75.	3.97	18.2
9.	N., -----	7,999	22.5	3,290	-16.35	4.03	19.4
10.	Check, -----	7,472		4,574		3.48	
11.	Acid P., -----	6,623	-7.38	3,790	-15.46	3.49—	-1.7
12.	Raw P., -----	4,443	-34.97	2,895	-31.07	3.29	-8.9
13.	Check, -----	6,509		4,300		3.68	
14.	Manure, -----	7,411	23.	2,618	-33.55	4.30	21.6
15.	Lime, -----	3,788	-31.7	2,250	-37.17	3.73	9.6
16.	Check, -----	5,064		3,221		3.26	

¹The growth summary in Table XXIX also includes the data from the fertilizer portion of experiment 337, containing 180 trees, 3 years of age.

Table XXIX.—INFLUENCE OF FERTILIZERS ON YIELD AND GROWTH IN APPLES.

(Summary of experiments, 336,338,339.)

Plot.	Treatment.	Yields, 1908-10. Lb.	Benefit yield, 1908-10.	Yields, 1910. Lb.	Benefit yield, 1910.	Aver. increase per tree in trunk girth, 1908-10. In.	Benefit growth, 1908-10.
1,-----	Check, -----	5,429	%	3,780	%	2.82	%
2,-----	N. P., -----	11,607	83.3	4,313	9.82	3.39	15.7
3,-----	N. K., -----	10,115	43.72	3,000	-26.36	(4.57)- ²	(50.3)- ²
4,-----	Check, -----	7,841		4,221		3.15	
5,-----	P. K., -----	9,856	33.85	5,207	37.67	3.04	-7.9
6,-----	N. P. K., -----	13,018	89.08	3,628	8.52	3.86	12.2
7,-----	Check, -----	6,408		2,905		3.59	
8,-----	Manure, -----	16,551	126.5	9,613	176.0-	4.25	25.4
9,-----	Lime, -----	10,913	33.-	5,453	34.27	3.8	19.5
10,-----	Check, -----	9,107		4,639		2.98	

1. The growth summary here also includes the data from the trees of the fertilizer portion of experiment 337.

2. The growth increase shown on this plot appears so large that the showing is probably due to an inaccuracy somewhere, though we have been unable to find it thus far.

Table XXX.—INFLUENCE OF FERTILIZERS ON AVERAGE SIZE AND COLOR OF FRUIT.

(Summary from experiments, 215,216,220.)

Plot.	Treatment.	Average size, 1908-10.	Benefit size, 1908-10.	Average size, 1910.	Benefit size, 1910.	Colored $\frac{1}{2}$ or more.	Benefit color, 1908-10.
		OZ.	%	OZ.	%	%	%
1,-----	Check, -----	5.23		5.54		70.5	
2,-----	N. P., -----	5.28	-1.13	5.74	-.6	51.7	-20.5
3,-----	N. K., -----	5.57	2.22	6.206	3.27	59.5	-14.4
4,-----	Check, -----	5.57		6.246		75.2	
5,-----	P. K., -----	5.86	8.92	6.24	3.5-	71.9	.13
6,-----	P-K ₂ SO ₄ , -----	5.52	6.56	6.03	7.4	63.7	.37
7,-----	Check, -----	4.98		5.59		64.9	
8,-----	N. P. K., -----	5.62	5.84	6.38	9.7	45.8	-20.37
9,-----	N., -----	5.1	-9.74	5.554	-8.05	47.06	-20.39
10,-----	Check, -----	5.98		6.261		63.8	
11,-----	Acid P., -----	5.8	-.86	6.42	4.72	70.8	3.8
12,-----	Raw P., -----	5.65	-1.39	5.95	-.67	75.1	9.8
13,-----	Check, -----	5.61		5.86		73.6	
14,-----	Manure, -----	5.93	4.22	6.88	14.	56.8	-9.4
15,-----	Lime, -----	5.73	.17	6.004	-3.35	71.0	2.2
16,-----	Check, -----	5.86		6.39		71.4	

Table XXXI.—INFLUENCE OF FERTILIZERS ON AVERAGE SIZE AND COLOR OF FRUIT.

(Summary from Experiments, 336,338,339.)

Plot.	Treatment.	Average size, 1909-10.	Benefit size 1909-10.	Average size 1910.	Benefit size, 1910.	Colored $\frac{1}{2}$ or more	Benefit color, 1909-10.
		oz.	%	oz.	%	%	%
1.	Check,	3.46		4.09		58.8	
2.	N. P.,	3.55	4.10	4.19	2.27	37.9	-18.0
3.	N. K.,	3.72	10.71	4.57	11.37	38.2	-14.9
4.	Check,	3.31		4.11		50.4	
5.	P. K.,	4.09	24.7	5.04	26.6	53.4	2.1
6.	N. P. K.,	3.58	10.15	4.30	11.67	37.0	-15.2
7.	Check,	3.22		3.72		53.2	
8.	Manure,	4.58	41.8	5.52	47.0	41.6	-12.4
9.	Lime	4.23	30.5	4.65	22.8	52.8	-2.1
10.	Check,	3.25		3.82		55.7	

Methods of Obtaining Above Results.—The data on yield given in Tables XXVIII and XXIX were obtained by weighing and recording to each tree all the fruit produced in the three years indicated. The data on growth in the same tables were obtained by measuring all of the trees at the time of starting the experiments, and again three seasons later. The average increase per tree on the different plots is then found and used as the basis for determining the per cent. of benefit on the treated plots.

The per cents. of benefit in all cases are determined by comparing the actual results secured on a treated plot with the "normal performance" of that plot. The "normals" for the plots are obtained by comparison with the two nearest checks. Thus if check plot I produced 65 bushels of fruit and check plot IV produced 95, the normal production of plot II would be considered as 75 bushels and plot III as 85. In other words, the variation in productivity is assumed to be gradual between plots. These normals for the treated plots are then compared with the actual results obtained from them; and the per cent. of benefit for each treated plot is thus determined upon the basis of its own normal production.

This method of normals is not without its shortcomings, some of which are indicated later; and it may in time be necessary to check it up at least, by the method of averages, the averages for the check plots being formed after excluding any that are evidently abnormal. For the present, however, the method of normals obviously fits our conditions better than any other that the writer is aware of.

The data on color and average size, given in Tables XXX and XXXI, and in all other tables of our results, are obtained by the random sample method. It was manifestly unnecessary and impossible, with the time and labor at our disposal, to count all the apples picked and to estimate and record the amount of color on every

fruit; and yet we desired approximately accurate comparisons. It was to meet that situation that the random sample method was employed.

In this method, a sample is taken at random from each basket of fruit as it is weighed; this sample is placed with other similar samples, enough fruit being taken from each basket to make a total of one or two bushels in the total sample from each plot. The total sample is then weighed and the apples are sorted for color. This sorting is done on the basis of extent of color rather than intensity, because the former is much more sharply distinguishable; and, in general, within a variety in a single locality, the latter is usually closely correlated with the former in any case.

In the sorting, all fruits that are colored one-half or more are placed in one class, while those colored less than half are placed in the other. This process, of course, carries some color into the uncolored class, and vice versa; and it also requires steady judgment throughout a given experiment; but on the whole it has given very satisfactory results. The per cent. of fruits in the colored class is considered to represent the relative amount of color in the plot as a whole. From these percentages, the per cents. of benefit are obtained on the "normal" basis described above.

The accuracy of this random sample method, of course, increases with the number of fruits in the sample. In most cases our numbers have seemed to be large enough, but as the yields increase it is probable that larger samples will be required.

General Discussion of Results.—In the case of yield and size in the above tables, the results for 1910 are included to enable one to see the present trend and relative constancy in the effects of the various treatments. In general, in these and the following tables, the details of our results are sufficiently clear in the tables, so that our discussion may be largely confined to the broader or less obvious phases, and to some of the principles apparently underlying the particular results obtained.

In most cases, the effects are seen to be fairly constant. In yield, in Table XXVIII, the marked exceptions are manure and nitrogen when used alone. In these a decided falling off in effect is noticeable in the third year. There is also a marked increase in effect from the phosphate-potash combination in plot 5 of this table. This high showing of plot 5 is not fully maintained in Table XXIX, though it is steady and creditable there; and it may come up with increasing age as in XXVIII, in which the experiments are a year older. We suspect, however, that part of the extra high showing of plot 5 in XXVIII is due to the relatively poor showing thus far of its adjacent checks.

Lime and raw phosphate or "floats" continue steady in their apparent injury to yield, in Table XXVIII; while the former is similarly steadily beneficial in XXIX. Here again it would seem that the apparent injury of lime and floats in XXVIII is at least partly due to the unusually good yields obtained from checks 10 and 13, with which plots 12 and 15,—especially the former,—are compared. Any additional reasons for the poor showing that may exist are subjects for later study.

In Table XXVIII, it will be observed that manure has fallen off badly on yield in the fourth year, while the plots receiving nitrogen

in combination with other minerals are still showing strongly. It will also be observed, in Table XXIX, that these conditions are reversed in 1910, which is the third year for the experiments recorded in it. From the evidence to date, we suspect that this is largely attributable to the quicker action of the nitrates as compared with the manure, which thus brings their full crops in about the second and fourth years, with corresponding relatively light crops in the third and fifth years. The action of the manure on the other hand is likely to be about a year behind the nitrates in both respects.

In support of this, and to show that the drop in efficiency of the nitrates in the experiments of Table XXIX is only temporary, we present herewith certain blossoming data of the current year, 1911. These data are from experiment 338, which is the oldest and most influential of the experiments in this group. The per cents. of full bloom on the various plots was as follows:¹ Plot I, 5 per cent.; II, 90 per cent.; III, 95 per cent.; IV, 2 per cent.; V, 25 per cent.; VI, 90 per cent.; VII, 15 per cent.; VIII, 75 per cent.; IX, 12 per cent.; and X, 1 per cent. Inasmuch as plots I, IV, VII and X are checks and plots II, III, and VI are those receiving nitrates, it is evident that the prospects for the latter during the present year are exceptionally bright.

Also the apparent drop in efficiency of nitrogen, that we do observe, is doubtless connected in considerable part with the very dry conditions that have existed for the past three years in most of the localities where our experiments are situated. It is well known that lack of moisture is very often the limiter in many crops. This is especially true in some of our nitrogen plots, where the heavy foliage has proved a severe competitor with the fruit for such moisture as was available.²

The data on size, in Tables XXX and XXXI, are surprisingly constant with each table, as is seen by comparing the size-benefits in 1910 with those in the three-season averages; but the extent of the benefit is much greater in the experiments of the latter table. All this is surprising to the writer, because, at the close of the second year of our experiments, attempts at correlating size with applications of plant food had proved entirely fruitless; and we concluded at that time there was no definite connection between them. It still appears, however, that under certain conditions, indicated later, the size of the crop and the moisture supply are the dominant factors influencing the average size of fruit.

It is also probable that the action shown for the various minerals in these tables, will still be found to be indirect and due rather to their relation to one or the other of the factors just named. For example, potash is shown here to have a distinct value in increasing the average size of apples. But attention has been called above, in our discussion of the function of potash as a mineral nutrient, to the fact that it increases the osmotic strength of the cell sap and thus enables plants to absorb water or resist drought better. Droughty conditions have been a marked factor in these experiments for the past three years, which would give this reputed property of potash an ideal opportunity to manifest itself.

¹These observations were made on May 13, 1911, the date of full bloom, by Mr. J. B. Johnston, the owner of the orchard.

²See Figure 12; see also Pennsylvania Bul. 100: 12.

The action of manure may also be due to its relation to moisture. Besides containing potash, it is well known that manure has some capacity to absorb and conserve moisture through its humus content. But whatever the reason may be, its beneficial effect on size may evidently be very marked at times, as shown especially in Table XXXI, where the average size shows an increase of over 40 per cent. The relation of lime to size of fruit shown in the latter table is rather anomalous, especially in view of its low content in fruit composition, and we do not attempt to account for it now. Its influence is practically nothing in Table XXX.

Nitrogen, however, which is fairly high in fruits, appears to reduce rather than increase the average size of apples. It also constantly reduces color. Both influences are probably indirect, however, as will be brought out later.

Values of the Individual Nutrients.—In the last four tables, we have seen the field effects that have followed the application of certain combinations of mineral nutrients, although in some cases a nutrient has been applied singly. The results in those tables, taken directly from the trees, may be considered a close expression of the values thus far, of the various materials used, whether singly or in combination.

In many cases, however, we may wish to know which is the more active element in a given combination, and approximately what values are to be assigned to each of the elements in it. Thus, in plot 2 of Table XXIX, we find a benefit of 83 per cent. resulting from an application of nitrogen and phosphate. Here the question arises as to how much of this effect is due to nitrogen and how much to phosphate. Any answer to this can, of course, be only an approximation of the truth, hence the values obtained in the following table, XXXII, are not to be taken too literally. They are of interest, however, and are the closest answer to the question above that we are able to give at this time.

In Table XXXII, the individual values, shown for the different materials when used in combination, are calculated from the data of the four preceding tables. Their values when used alone are secured directly from those tables. In particular, the values "in combination" are calculated from the per cents. of benefit obtained in plots 2, 3, and 5. The value of nitrates,¹ for example, is found by following the formula $(NP + NK - PK) \div 2$. In other words, the per cents. of benefit obtained in plots 2 and 3 are added, from this sum the per cent. of benefit in plot 5 is deducted, and the remainder is divided by 2. The quotient is considered to be the value of nitrates in the combination. The other values "in combination" are obtained similarly.

¹Nitrogen is referred to here as nitrates to avoid confusion when considered "in combination" and "alone." There is of course no evidence that green plants can use nitrogen in any other way than in some form of chemical combination.

Table XXXII.—INFLUENCE OF FERTILIZER ELEMENTS ON YIELD, COLOR, SIZE AND GROWTH.

(Estimated per cents. of Benefit.)

(a) Expts. 215,216,220.	Yield.		Color 1908-10.	Size 1908-10.	Growth 1907-10.
	1908-10.	1910.			
Nitrates, ¹ in combination, -----	34.6 %	21.7 %	-17.5 %	-3.92	12.1 %
Nitrates, alone, -----	22.5 %	-16.35 %	-20.4	-9.74	19.4
Phosphates, in combination, -----	41.4	52.5	-2.9	2.79	-3.2
Phosphates, alone, -----	-7.4	-15.4	3.8	-.86	-1.7
Potash, in combination, -----	42.0	49.5	3.1	6.13	7.0
Manure, alone, -----	23.	-33.5	-9.4	4.22	21.6
Lime, alone, -----	-31.7	-37.2	2.2	.17	9.6
(b) Expts. 336,338,339.	1908-10.	1910.	1909-10.	1909-10.	1908-10.
Nitrates, in combination, -----	46.6	-27.1	-17.5	-4.94	36.95
Phosphates, in combination, -----	36.7	36.9	-.5	9.04	-21.25
Potash, in combination, -----	-2.86	.75	2.6	15.65	13.35
Manure, alone, -----	126.5	176.	-12.4	41.8	25.4
Lime, alone, -----	33.—	34.3	-2.1	30.5	19.5

1.- The nitrogen, as already stated, was applied in the form of dried blood and nitrate of soda. It is here called nitrates, however, to avoid misunderstanding.

Since these results are derived from Tables XXVIII to XXXI, they are naturally not materially different. The exhibit is more compact, however, and the values of the individual nutrients stand out more sharply.

The data on color in the two sections of this table, (a) and (b), are notably uniform, both qualitatively and quantitatively. The same is true qualitatively, and partially quantitatively, in all the other data here, except that on potash and lime in the yields of both columns, and that on nitrates and manure in the yield column of 1910. An explanation for the lack of harmony in the latter case has already been offered above, in discussing the results of the preceding tables. The disagreement for the single year is probably connected with the biennial bearing tendency, coupled with the year's difference in age of the two sets of experiments.

The steady improvement with increasing age of the experiments in the effect of phosphates-in-combination upon yield, is one of the noteworthy features at the present time. When used alone, however, phosphates have apparently decreased the yield. Also with each of the other materials, it will be observed that they are appearing distinctly more effective when used in combination than when used alone.

The Occasional Harmful Effect of Potash and Other Fertilizers.

Certain apparently discordant effects of fertilizers are comparatively easily explained. Thus nitrogen, as shown above, is relatively steady in its improvement of yield and growth and its reduction of color and average size of the fruit. These facts can be fairly readily accounted for.

But it is the occasional anomalous effects,—those that appear one way in some cases and are reversed in others, such for example, as appear in the opposite effects of lime and of potash in the two sections of Table XXXII,—these are the effects that are baffling and that incidentally may be most worthy of study in any search for new truth.

Examining these lime and potash effects more closely, we see that they cross; that is, where one is beneficial the other is not, and vice versa. Thus in the experiments of section (a), potash gives an increase in yield of 42 per cent. for the three-year period and 40 per cent. in 1910, while lime in the neighboring plots is giving deficits of 31 per cent. and 37 per cent., respectively. In section (b), however, while potash is showing a deficit or no beneficial effect, lime is giving 33 per cent. and 34 per cent. benefits. The full significance of this, we do not attempt to point out at this time; neither can we guarantee the full continuance of the differences now observed. Indeed, we shall expect the potash deficit to disappear, for reasons indicated later, because of a heavy liming given to all the plots in Experiment 338,—the one in which the injury has been most apparent.

But the fact that a number of mineral elements, and potash especially, may have a harmful effect,—at least in certain forms or quantities, or in certain soils,—is not confined to this one observation.

We have observed some forty cases of severe injury or death to young trees in two of our experimental orchards. In these cases the injury seems to be largely connected with muriate of potash applications, though it is not entirely so. The general character of the injury as it appears on the twigs is shown in Figure 5. Under the title of "A New Disease on Apples," this disease was described in our last Annual Report,¹ as follows:

"A NEW DISEASE ON APPLES."

"This disease is apparently physiological, and appears most conspicuously as an affection of the twigs of the current season's growth, though it is not confined to them. The twigs lose their normal color and become dull and of a rather blistered and mottled appearance at first. At a casual glance the effect somewhat resembles that produced by an incrustation of the San José scale. Immediately under the epidermis of the diseased areas and extending about half way to the cambium, in the early stages, there are numerous small, brown spots or pits where the tissues are dead or dying. Later, on the surface, the epidermis usually cracks around and over the diseased spots and they become rough, dark, and rather scab-like, and are usually slightly sunken through the drying out and death of the tissues underneath. In some cases the cracks may go deeper and involve the wood. The leaves are also affected sooner or later, probably through the girdling of the twigs below them. They turn brown, dry out and crumble, beginning at their tips and outer margins. In time, the twig, limb or whole tree may be killed.

"The disease usually becomes well developed and conspicuous by the middle or latter part of August. The appearance of the affected twigs taken on August 20 is shown in figure 1." (Same as our present Figure 5.)

"Specimens of the disease referred to our pathologist, Professor H. R. Fulton, were thought to closely resemble Sorauer's 'Tanbark' disease (Loh Krankheit). But specimens taken early in the following season and sent to Sorauer in Germany were pronounced by him not to be the disease referred to. The disease is, therefore, unnamed as yet. This is the first record of its occurrence on apple trees in this country, so far as we have been able to learn, although there is evidence that it is similar in nature and origin to severe or fatal maladies which have been noted in other states on peaches and pineapples. Our present evidence points strongly toward its connection with heavy applications of a certain fertilizer."

¹See Annual Report of the Dept. of Exptl. Horticulture, in Penn. Sta. Report for 1909-10.

Fig. 5. Apple Twigs Affected with an Apparently New Physiological Disease. (See text).



Since writing the above description our attention has been called by our assistant, Mr. H. F. Hershey, to the possibility of this disease being identical with that described under the title of "Oedema of Apple Trees" by professor George F. Atkinson,¹ in 1893. Specimens submitted to him, however, have thus far been pronounced not to be the same as the disease described by him.

The disease, therefore, is still unnamed; but as this can be done better after the cause is known, we are continuing our search for the latter since it is the important matter anyhow. At present, the evidence still points to a connection between the disease and fertilizer applications, as will appear later, though potash is apparently not the only offender.

Another observation that is very interesting in this connection is one made in experiments upon peaches by Professor L. C. Corbett in West Virginia, during 1899 to 1904. These results have not been published as yet, but notes giving the data were kindly loaned by him to the writer. In these experiments it was found that peach trees were readily killed with applications of 2½ pounds per tree of muriate of potash, on old ground, while they were benefitted by similar applications, on new ground. With sulphate of potash similar results were obtained, but 5 pounds per tree were necessary to accomplish this; 4 pounds being only sufficient to cause considerable injury.

This difference in amount required to kill the trees is probably due merely to the marked difference in solubility of the two materials, the muriate in water at normal temperatures being over three times as soluble as the sulphate.² This would doubtless result in a lower rate of absorption in the peach, as has already been shown to occur in the potato,³ besides reducing the opportunity for toxic dominance in the soil solution, referred to below.

These cases also show that the chlorine of the muriate is not the harmful agent, except perhaps in so far as it increases the solubility of the potash. The chlorine has been suspected, on account of certain relatively injurious effects following the use of the muriate on apples in Massachusetts,⁴ and also on account of similar effects from the muriate and the decided injuries from kainit in Florida upon pineapples.⁵

In these Florida experiments, also, they found that acid phosphate had an injurious effect on pineapples, which could be corrected by the use of lime. They attributed the injury to the sulphate of iron and aluminum which the acid phosphate contained, since P_2O_5 derived from genuine bone black did not have any injurious effects. Nitrate of soda when used in sufficient quantity to furnish all the nitrogen required proved injurious both to plants and to the shipping qualities of the fruit.⁵ Nitrogen from organic sources was beneficial, however.

¹Cornell Bulletin 61: 299-302. 1893.

²At 20° C, the ratio of solubility in water of KCl as compared with K_2SO_4 is 34:10. See Seldell, Solubilities of Inorganic and Organic Substances, pp. 241, 261. 1911.

³U. S. Bureau of Plant Industry, Bul. 45: 26. Observation is credited to Sjollemid, in Jour. f. Landwirtschaft., Vol. 47: 305.

⁴These results are given later, in our Table XXXIV.

⁵Florida Station Report for year ending June 30, 1909, pp. 25-26; also see Florida Bulletins 50, 83 and 101.

An Explanation of These Occasional Injuries.

In looking back over this discordant and anomalous series of effects, from the "crossed" results with lime and potash on yield; from the injuries to peach on old ground with materials that were beneficial on new ground; to the injuries on pineapples from different applications involving certain kinds of carriers, injuries which were eliminated by the addition of lime or by changing the carrier to others not having a mineral base,—looking back over this series, there is but one comprehensive explanation that suggests itself. In the West Virginia work, we have shown that the injury can hardly be due to the chlorine, except possibly indirectly, therefore it would seem of necessity to be due to toxicity of the bases. This toxicity of certain bases, when alone or distinctly dominant in a solution otherwise weak, and also the related fact of its mutual counteraction by the presence or addition of certain other bases, are both well established physiologic facts, as we have shown above.¹ The only new thing here is their connection with certain conditions in the field which have hitherto been unexplained.

Reviewing our facts with this in mind, we see that the potash is harmful where the lime content is low; hence lime applications there should prove beneficial, as they do. On the other hand, where potash is beneficial the lime content is probably already high, or at least sufficient; there, further additions of lime have apparently proved toxic. This is somewhat surprising, as lime in excess is not usually toxic. But it is not impossible, since cases of injury and death to young apple trees have been ascribed to lime-poisoning by Headden in Colorado.² The lime in our experiments is applied alone, at the rate of 1,000 pounds per acre annually, usually in the form of calcium oxid.

Under this view also, the injury to peaches on the old ground is explained as due to the fact that the soil solution there was relatively weak, thus permitting the potash to become unduly dominant, while in the new ground this did not occur.

The injury to pineapples from acid phosphate applications, which were neutralized by the addition of lime, is what would normally be expected under our present view. And the value of the change in carrier of the nitrogen probably consisted in the elimination of the toxic influence of the sodium base. This, if our view is correct, might also have been accomplished by the addition of lime, unless the sodium accumulation should become too excessive, a condition which is relatively easy on the sandy soils of Florida.

This basic toxicity view may also *help* to explain the observation above, that the value of each of the materials reported in Table XXXII was greater in combination than when used alone. Especially may this be true of *some* of the negative influences observable in the yields of 1910. But most of the single-year indications of injury are probably only apparent, and are really to be attributed to the biennial bearing tendency, as pointed out above. Moreover, the action of limiters and their removal is doubtless involved in the better showing of the materials when used in combination.

In general, however, we see that our present hypothesis is very effective in accounting for the otherwise baffling series of observa-

¹See section on "Toxic Action of Certain Bases and its Neutralization," pages 454-455.

²See Colorado Bulletin 131: 24-26. 1908.

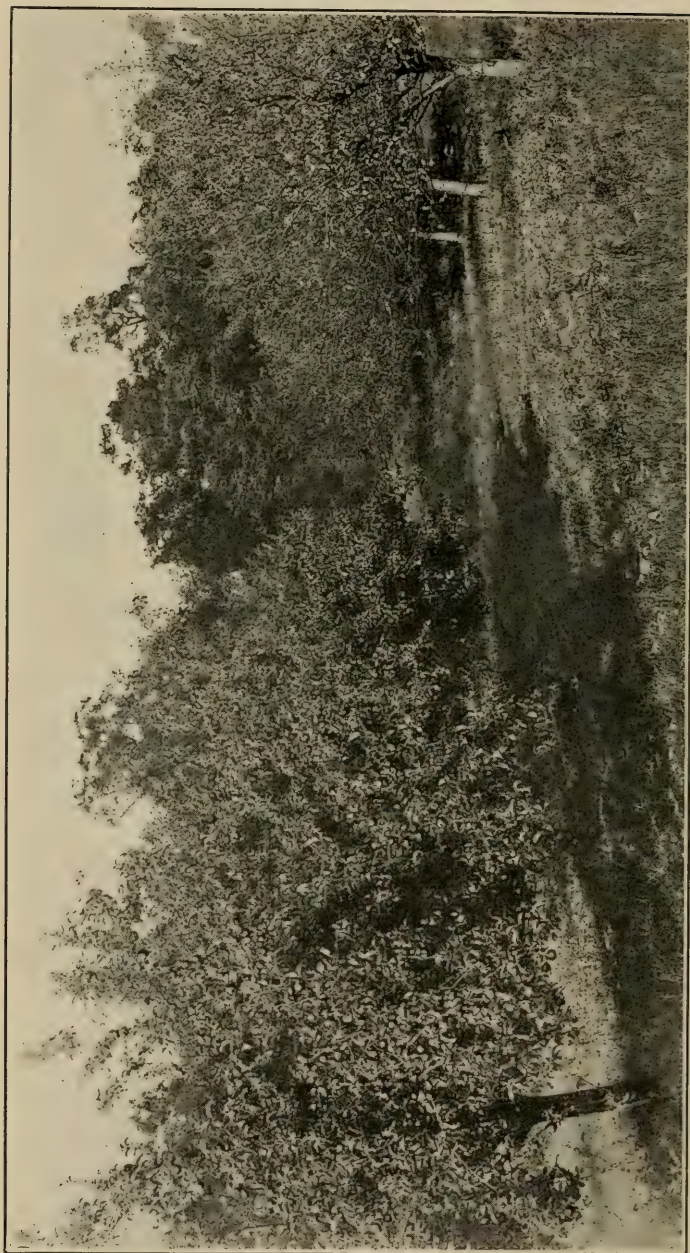


Figure 6. Manure vs. Nothing. A View in Experiment 220.

Row on left receiving stable manure, third year, produced 373.8 bushel per acre. Row on right, receiving nothing, produced 27.9 bushel per acre. Variety York Imperial.

tions recorded above. Its full proof, of course, will depend upon further analyses and experiments of a deductive character. These we can make in connection with our young apple trees especially, and it may be said in passing that thus far we have been unable to reproduce the disease on trees in another portion of our orchard, after it had been treated with two tons per acre of ground limestone.

The Appearance and Financial Gains in Certain Experiments.

This phase of the subject was touched upon in our Bulletin 100, written in 1910. The discussion there is repeated here with some slight modifications.¹

"Some of these plots as they appeared in the field during the past season are shown in Figures 6 to 9. Figure 6 shows a portion of plots 13 and 14 of Experiment 220. The latter plot has received stable manure for three years, [now four years] while the former has received nothing. The yield of the past year was nearly 374 bushels per acre on the manure plot and 28 bushels on the check. The variety here is York Imperial.

"Figure 7 is a view of one of the check plots of Experiment 338. Checks 1 and 4 produced at the average rate of 156 bushels per acre during the past year; while plots 2 and 3, located between them, produced 721 bushels per acre. Every tree on the latter plots was loaded with fruit and required heavy thinning and propping, while neither was required on any tree in the former plots. The contrast in both foliage and fruit was vastly more striking in the orchard than it appears in the figures. Plot 2, which is shown in Figure 8, received nitrogen and phosphate while plot 3 received nitrogen and potash. In all other respects the latter plots were identical with the checks enclosing them. Figure 9 shows a view between plots 1 and 2. The variety in this case is Baldwin.

¹Stewart, J. P. The Fertilization of Apple Orchards. Pennsylvania Station Bul. 100: 15-16, 1910.

The results shown in Figures 6 to 9, together with some of our other most striking results, are considered further in Table XXXIII.

Table XXXIII.—FINANCIAL VALUE OF FERTILIZATION.

(As given in our Bulletin 100.)

Expt. 221, 1909 (3rd year).	Yield, lb.	Bushels per acre.	Value at 50c.	Cost of fertilizer.	Net gain per acre.
Unfertilized, plots 4 and 7, -----	19,448	194.5	\$97.25	-----	-----
Com. Fertilizer, plots 6 and 9, -----	47,028	470.0	235.00	\$13.00	\$124.75
Manure, plots 5 and 8, -----	48,550	485.5	242.75	15.00	130.50
Expt. 220, 1909 (3rd year).					
Unfertilized plots 13 and 16, -----	291	27.9	\$13.85	-----	-----
Manure, plot 14, -----	1,947	373.8	\$186.90	\$15.00	\$157.95
Expt. 338, 1909 (2nd year).					
Unfertilized, plots 1 and 4, -----	2,607	156.4	\$78.20	-----	-----
Com. fertilizer, plots 2 and 3, -----	12,026	721.5	360.75	\$15.00	\$267.55

"It is to be noted that the net gains are obtained after deducting both the cost of the fertilizer and the value of the unfertilized crop. Also the fruit here is valued at 50 cents per bushel, while the actual prices obtained for it varied from 50 cents to \$1.25 per bushel, and any increase in the appraisement of the fruit of course will proportionately increase the net gain. It is also to be stated that in Experiment 338, especially, variations in the factors of tillage, spraying and pruning produced no material effect on the size of the crop, since the treatment of all plots in these respects was uniform, and tillage was varied in other portions of the experiment.

"Such striking results as these of course are not to be expected everywhere. They evidently occurred here because plant food was the crop limiter in these orchards. For any given case this can only be determined by experiment. These orchards are on three diverse soil types. The soil in one case was evidently "run down;" in another case it was in average condition; and in the third the soil condition was apparently above the average. These orchards are from 21 to 37 years of age and they are the only ones under experiment above 20 years old. Age, however, is not a sure index of the need of plant food, as one of our youngest orchards, a seven-year old, is responding strongly to fertilization, while some older ones have proved unresponsive. The big fact is that when such results as these are obtainable anywhere, it raises a strong suspicion that similar benefits may be obtained in many other orchards. And these

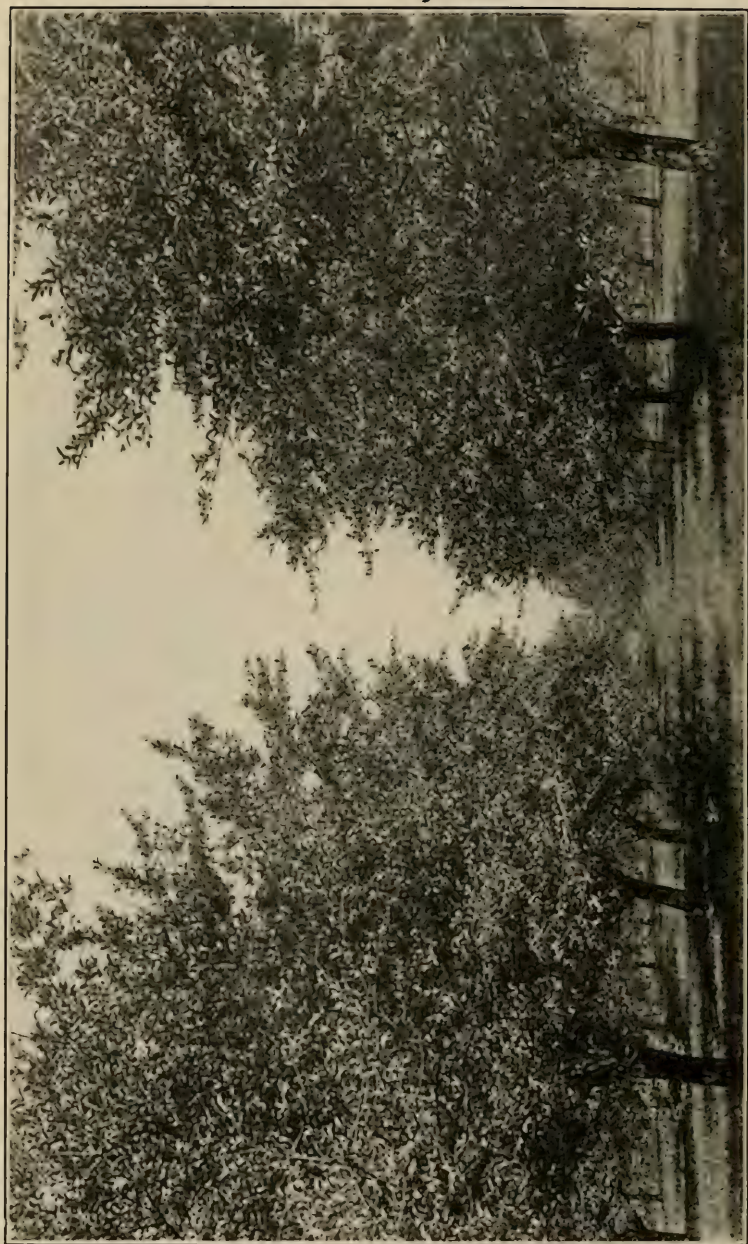


Figure 7. Commercial Fertilizer vs. Nothing.

A view between rows of Plot 1, in Experiment 338. These trees, adjoining those in the next figure, receive nothing and produced 136 bushels per acre in 1909. Variety Baldwin. Compare with Figure 8.

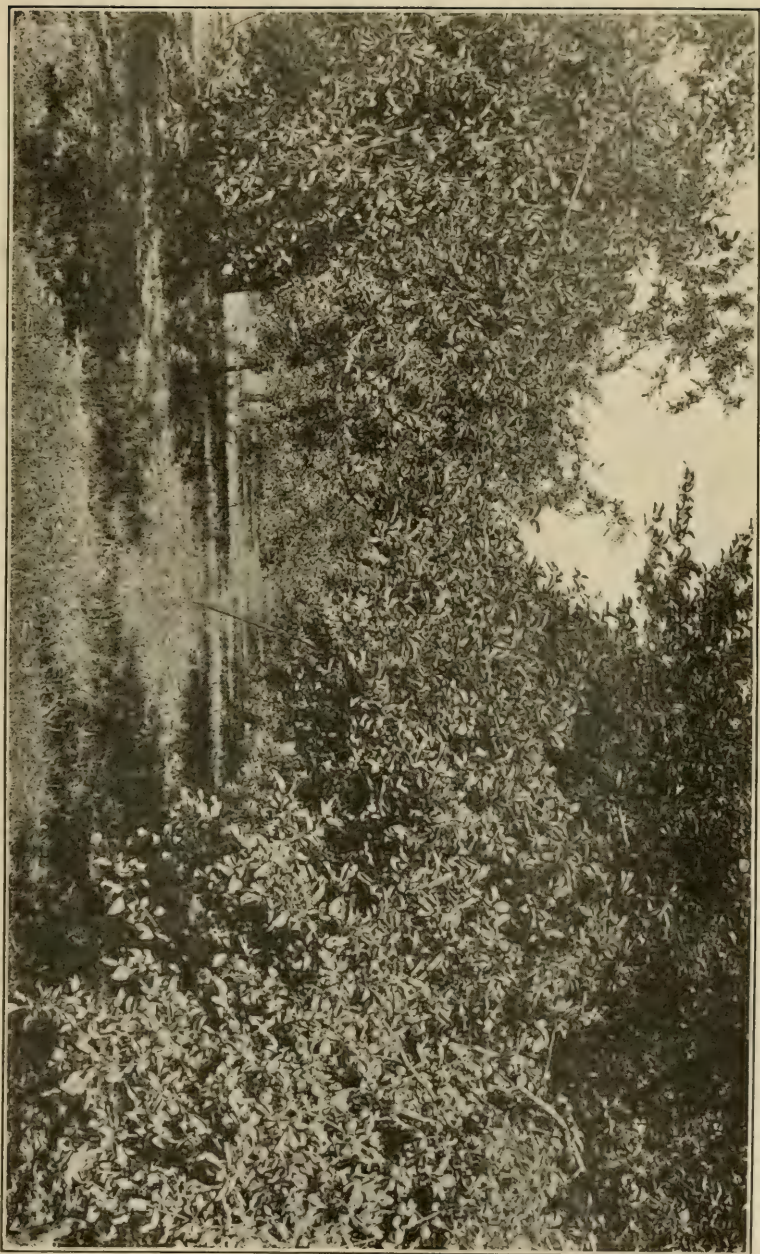


Figure 8. Commercial Fertilizer vs. Nothing.

A view between rows of plot 11, in Experiment 228. These trees received nitrogen and phosphate and produced 721 bushels per acre in 1909. The variety and handling in all respects, except fertilization, are identical with the trees in Fig. 7.

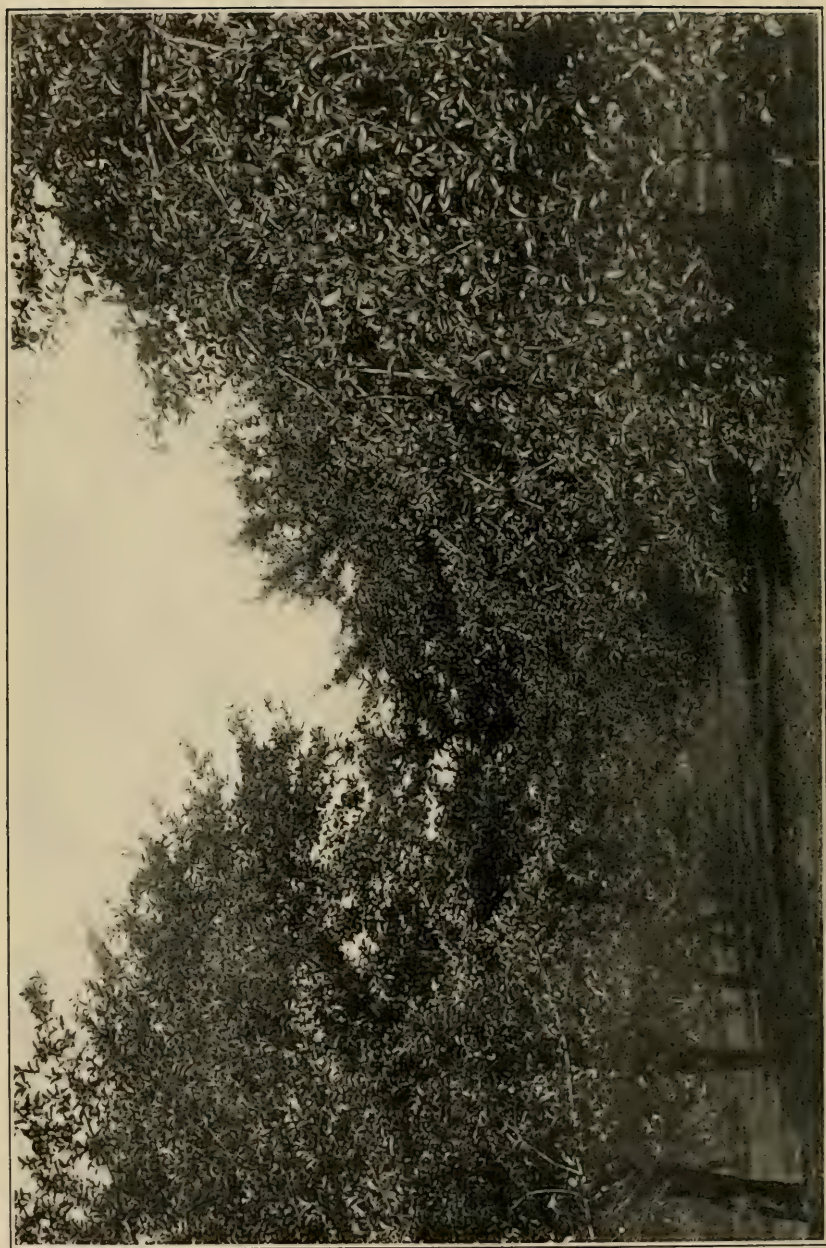


Figure 9. Commercial Fertilizer vs. Nothing.
A view between plots shown in the two preceding figures. The row on the left has received no fertilizer, that on the right has annually received nitrogen and phosphate. The net increase on the latter was \$267 per acre.

results show beyond peradventure that in some orchards apple trees, like other plants, respond strongly and directly to application of plant food.²

Effect of Different Fertilization on Foliage.—"The beneficial effect of nitrogen on foliage is generally recognized. It is not so widely known, however, that this effect is often materially increased by the further addition of the other ingredients, phosphate and potash, and also that the latter constitutes in the absence of nitrogen applications may exert a very marked influence. These facts are brought out in Figures 10 to 13, taken on October 20, 1909, and showing plots 4 to 9 of Experiment 220. All treatments have been in operation for three years.

"The effect of nitrogen on foliage appears much sooner than that of the phosphate-potash combination. The effect of the former appeared very distinctly within two months after the first application, which was made on July 8, 1907,¹ while with the latter materials the benefit scarcely became of importance until near the close of the third year.

"Besides the quick response to nitrogen which occurred here, other interesting results appeared. These trees in 1907 effectively resisted a severe drought and an attack of "frog-eye" leaf-spot, which early defoliated the untreated trees. They also came out into leaf much greener again the following spring and showed as marked differences in late May of 1908, before the second application, as they had shown in the preceding autumn.²"

Relation of Fertilization to Fire Blight.

This point has been under observation in our experiments for some years, and the existence of any relation has been questioned in some quarters. Up to the third or fourth year, and even yet in some experiments, there seemed to be little relation between fertilization, with its resulting differences in succulent growth, and fire-blight. In the later years, however, a marked relation has appeared in certain experiments. The manured plots and those in general that have been making the most vigorous growth are distinctly more affected with blight than those making less growth. Thus in Experiment 216 during the fourth year, the manured plot contained decidedly more blight than all the remaining plots in the experiment. In Experiment 220 during the current year (the fifth), the only blight observed in the Baldwin section was on the manured plot. During this same year in Experiment 219, the blight was by far the worst on plots 8 and 9,—those receiving mulch and manure, and mulch and complete fertilizer. These plots have uniformly been the most vigorous in this orchard.

It is true that blight sometimes appears on trees that are receiving very poor treatment and are consequently making very poor growth. This is probably attributable to previous infections with considerable canker formation, thus giving an abundant and immediate source of infection, or to special susceptibility on the part of the variety. Such cases, however, evidently do not prove that the character of the growth has nothing to do with blight injury, and our observations above furnish direct evidence that the latter relation does exist.

¹It was applied in the form of nitrate of soda as a top-dressing. It was left uncultivated because of the fact that parts of the experiment are so rough and stony as to render tillage impossible.

²The above section is quoted from the writer's Pennsylvania Station Bulletin 100, p. 25.

Orchard Fertilization in Massachusetts.

In the tables above, we have given data from *extensive* work during the relatively short period of four years. Its value consists chiefly in the duplications, the relative constancy of its results, and the large amounts of fruit and numbers of trees and soil types concerned. In the next table, we have data from the reverse conditions,—one experiment continued over 22 years.

These data were kindly furnished to the writer by Director William P. Brooks, of the Massachusetts Experiment Station. The experiment has been running at the Massachusetts Station during the last 22 years. The trees were planted one year after the experiment was started and the plots contain three trees each of Baldwin, Rhode Island Greening, Roxbury and Gravenstein. The soil is a "moderately heavy, gravelly loam with a moderately compact (clay) subsoil," and is stated to have been "highly exhausted, chiefly by the production of hay, before the experiment started."

Table XXXIV.—FERTILIZATION OF APPLES IN MASSACHUSETTS.

(Treatment and Total Yields per Acre from 1889 to 1911.)

Annual Treatment.	Plot 1. Manure 10 tons.	Plot 2. Wood ashes ton.	Plot 3. Check.	Plot 4. Bone and muriate, 600 and 200.	Plot 5. Bone and low-grade sulfate, 600 and 400 lb. per acre.
Average girth, -----	38.25 in.	33.23 in.	27.98 in.	32.27 in.	37.02 in.
Ratios, -----	136.7	118.8	100.	115.3	132.3
Yields, lb., -----	26,203.5	14,500.5	4,562.	14,811	22,245.5
Ratios, -----	574.4	319.1	100.	324.6	487.6
Color and size, -----	4	1	5	3	2

These results are similar to and corroborate those recorded in the preceding tables, with the differences in some cases even more distinct. In every respect the treated plots have proved markedly superior to the untreated. The manure plot, which alone receives nitrogen in quantity, leads in yield and growth but falls next to the check in quality. It is closely followed in yield and growth and much surpassed in quality by plot 5, which received ground bone and low grade sulphate of potash. The superiority of 5 over 4 which differs only in the carrier of the potash is very interesting. The former has produced about 50 per cent. more fruit and over 15 per cent. more growth than the latter during the whole period of the experiment. There has been some question at the Massachusetts Station as to whether this is due to the magnesia in the low grade sulphate, or to a harmful effect of the chlorine accumulating from the muriate, or to a soil difference.

A year ago we should have been inclined to credit it to the chlorine in the muriate, on account of certain constant superiority in our sulphate plots over the muriate, in the third year's results. In

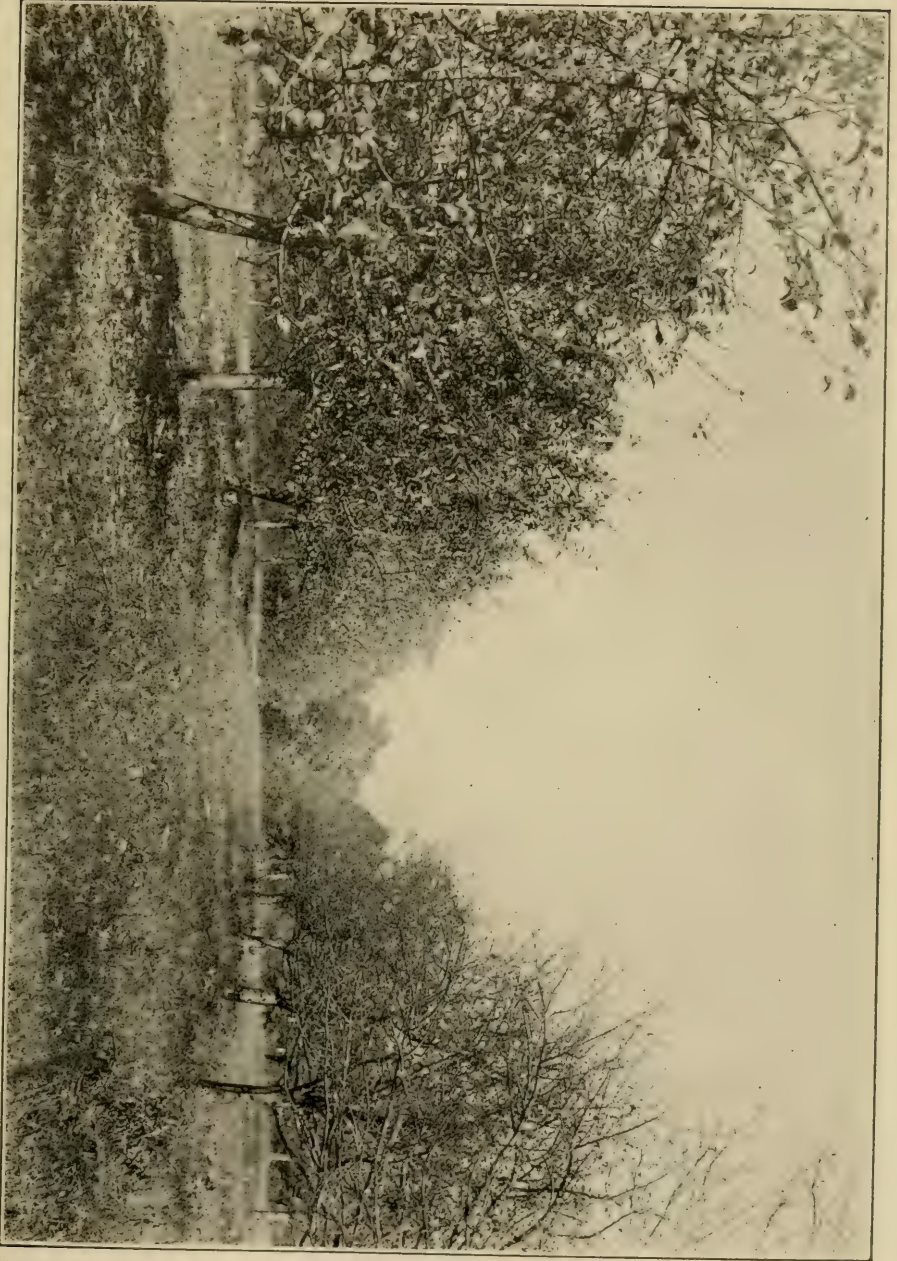


Fig. 10. Phosphates and Potash (muriate) vs. Nothing.
The row on the left, plot 5, has received the fertilization, with potash in the muriate form, while that on the right, plot 4, has received nothing.

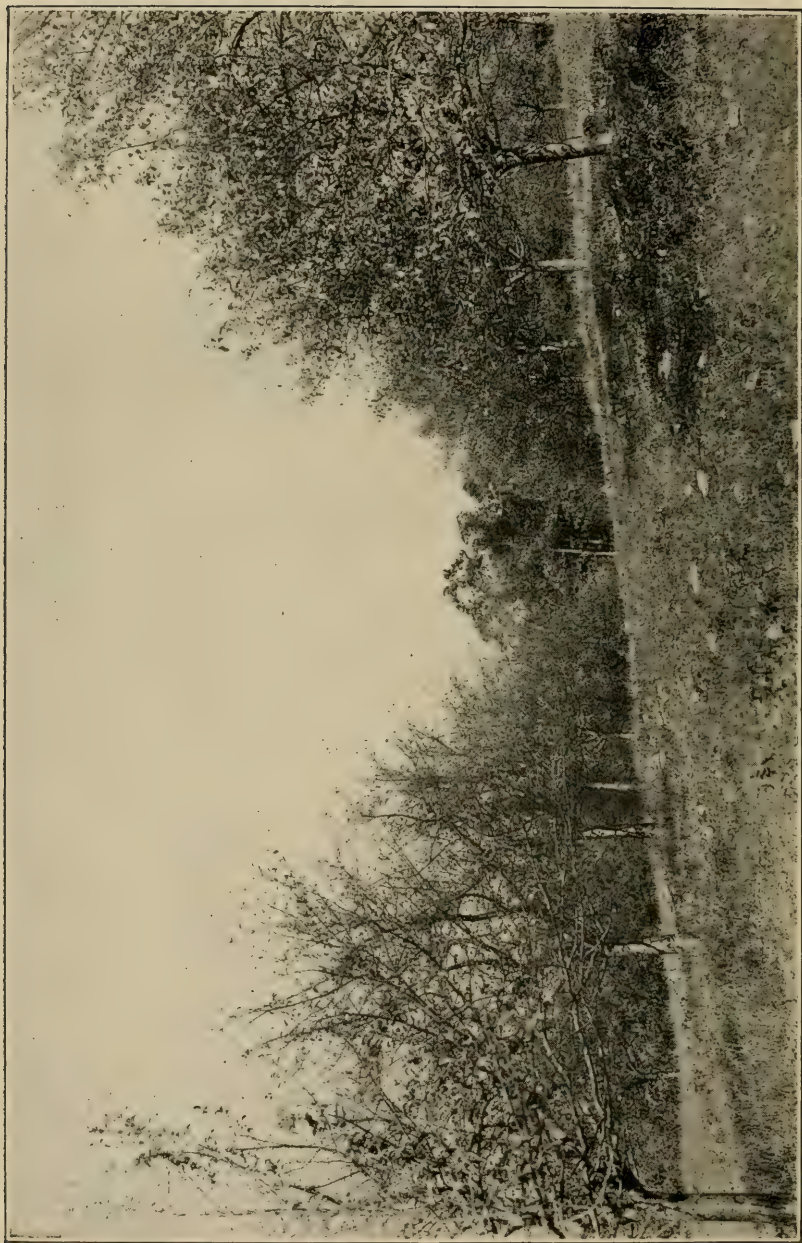


Fig. 11. Phosphates and Potash (sulphate) vs. Nothing.
The row on the right, plot 6, has the fertilization, while that on the left, an unfertilized row, has received nothing except what was carried from the row above by drainage and leaching.

Tables XXVIII to XXXI, however, it will be observed that this superiority has now vanished, and therefore we cannot charge the reduction and injury to the chlorine, except possibly indirectly, as indicated above, by rendering the potassium base more soluble. According to our present basic toxicity view, the reduction in yield on plot 4 is due to an excess of potassium ions in solution; and if this is true, it should be capable of correction by proper applications of lime.

Some Results from Tree Injections.

Further results from manurial applications upon apple trees are given in connection with Experiments 217 to 221 (excepting 220). Before leaving the present discussion, however, which deals more directly with mineral nutrients in their relation to tree-feeding, it has seemed well to give some attention to the subject of tree injections, with special reference to their probable value and present results. Nothing of this sort has been done, as yet, in connection with our own experiments, but considerable experimental work has been done elsewhere. Very little of this work has been directed exactly at the question of fruitfulness, however, most of it being along the line of tree medication or rejuvenation, but the results observed are of interest in showing approximately what may be expected from such operations.

The earliest work that has come to the writer's attention is that of a Russian, Mokrzhetski, reported in Russian periodicals in 1903 and abstracted in the Experiment Station Record Vol. XVI, p. 932. Under the heading of a "New Method of Healing and Nourishing Trees," he described briefly his results from injecting various nutritive salts, both dry and in solution, into some five hundred trees. Tests were made upon oaks, poplars, frost-injured sycamores, diseased acacias, grapes, pears and apples. Iron sulphate is reported to have been successfully used against chlorosis, anthracnose of grape, and some fungus diseases of the apple. Solutions of acetic, oxalic, and tartaric acids were used against gummosis; and solutions of arsenic, copper sulphate, manganese, and barium are said to have been used more or less successfully in combating the bark beetle and a species of aphids.

In France, Simon injected solutions of nitrate of potash, copper sulphate, purin, and sap-like solutions into the trunks of rather decrepit apples, peaches, vines and potatoes, with marked rejuvenating effect in most cases.¹

He was followed by Fron, working on pears and using solutions of iron sulphate and calcium nitrate.² Fron found that while the vigor of trees could usually be rather markedly increased, yet the improvement was mostly confined to a relatively small portion of the tree, and his net conclusion was that the method was of little practical value, though it might after several years serve as a guide for determining which elements should be added to the soil.

In America the earliest work apparently is that of Bolley.³ He used many substances and concludes "that formaldehyde, copper

¹See The Gardener's Chronicle (London), Third Ser., 41 (1907), No. 1045, p. 8.

²See Journal de la Societe National d'Horticulture de France (Paris), Fourth Ser., 10 (1909), pp. 54-59.

³See Reports of North Dakota Station for 1904 and 1907.

sulphate and iron sulphate, when properly applied, tend to hasten the recovery of apple trees from sunscald and sour heart, and to check the development of apple blight." The formaldehyde was used at strengths varying from one-half part to 2 parts per 1000 of water, the rapid-absorbing trees requiring the weaker solutions. He reports increased vigor and fruiting in the treated trees, but states that care is demanded to avoid injury, and the resistance of trees to this injury was apparently extremely variable.

Other work in this country has been done by Chandler at the Missouri Station, testing the effect of potash salts on the hardness of peach trees; and experiments on the value of injections in the control of fire-blight, especially in nursery trees, are in progress by V. B. Stewart at the Cornell Station. In the last-named work, various fungicidal solutions have been readily taken up by the young trees through tubes attached to cut-off branches, but the result has usually been serious injury to the tree, even with solutions as dilute as one part of copper sulphate to 2000 parts of water. Similar serious injury to the young trees resulted from corrosive sublimate at 1 to 500; lime-sulphur at 1 to 200; and a slight injury resulted from injections of potassium permanganate at 1 to 2000. Hence, little hope of success with injections of such inorganic materials is now entertained.

The whole subject of tree-injections is thus seen to be in a rather unsettled state. The fact has been clearly established, that with a proper arrangement of tubes and receptacles, trees in foliage will readily take up considerable quantities of soluble salts. Nutritive salts or solutions in moderate amounts are frequently beneficial, though the effect seems to be more or less confined to one portion of the tree. Certain poisons, when used in extremely weak solutions, may be stimulative to trees, as they are to animals and other plants, and they may afford protection against certain diseases, though the evidence is not at all clear on this point, and their use must be attended with great caution. The problem is evidently one for the investigator, and one that requires much more study before anything definite can be offered to the practical orchardist.¹

¹Part of the above section on tree-injection appeared in an article by the writer in the *Rural New Yorker*, 1911: 258.



Fig. 12. Nitrogen, Phosphate and Potash vs. Nothing.

The row on the left, plot S, has received the fertilization, while that on the right has received nothing. Scarcely a leaf had fallen on plot S when the picture was taken, October 20, 1909, and the foliage was very deep green and luxuriant. It was in competition with this foliage that the fruit failed to attain size.

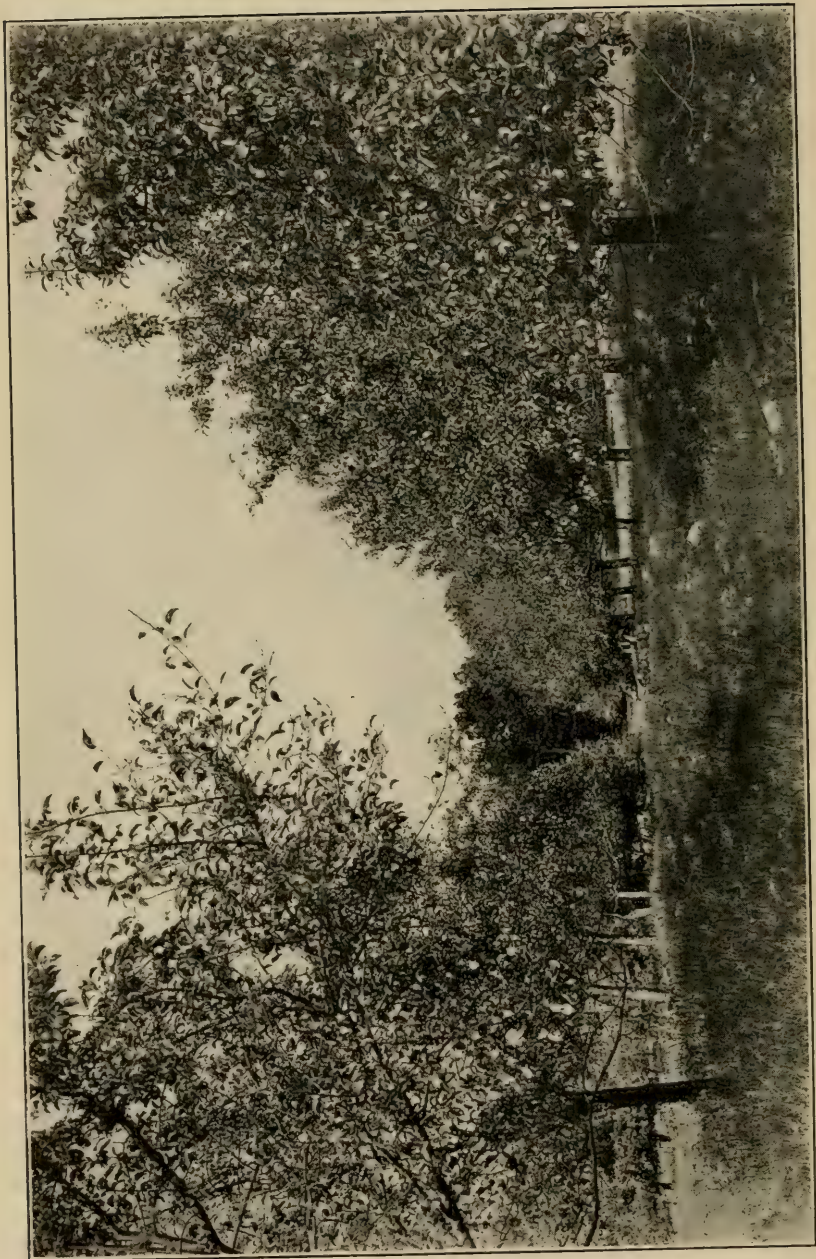


Fig. 13. Nitrogen (on right) vs. Nothing.
The row on the left is an unconsidered row in this experiment, and receives no fertilization except through leaching from the nitrogen plot above. This has been sufficient to produce quite distinct effect, however. Some leaves had fallen on the nitrogen plot, and their color was not so deep green as in plot 8.

BIBLIOGRAPHY: EXPERIMENTAL WORK ON APPLE TREE FERTILIZERS, &c.

The more important papers dealing with the results of fertilization and injection experiments upon apples and other fruits or allied plants are given below. We have made abstracts of these reports in nearly all cases, but space and time do not permit their insertion here. Some references have been included that have only a remote bearing upon apples directly, but they are entered because they contain some phase of the general subject of crop fertilization which seemed worthy of note in this connection.

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CULTURAL METHODS AS A FACTOR IN APPLE PRODUCTION.

With apples as with other crops, probably the chief function of cultural methods is the proper control of soil moisture. Other associated functions, such as promoting nitrification and killing weeds, are important,—sometimes more so than moisture control,—but the latter is usually the chief consideration.

This is especially true of fruit trees. In them the moisture demand is large, both for use in transpiration and as a constituent of the fruit and vegetative parts. Hence a shortage in water-supply may occur very frequently in orchards, at least for limited periods during the season. In such cases, it may act very completely as the limiting factor and thus reduce or nullify the effect of all other operations in the orchard. Such an action has already been indicated as occurring in some of our fertilizer plots and it is quite probable that some of the failures elsewhere to get satisfactory returns from plant food applications have been due to a deficient moisture supply.

It is true that some treatments with fertilizers, notably potash and apparently nitrogen to some extent, often have a tendency to reduce the evils of drought, at least so far as growth is concerned. This has been noted in our discussion of mineral nutrients, and also has appeared in some of our experiments. In general, however, we believe that a deficient moisture-supply is much more likely to reduce the efficiency of fertilization than the latter is to compensate for the former.

Since the questions of moisture and plant food are thus so closely associated, our experiments upon cultural methods have been planned so as to give data not only upon the methods themselves but also upon these methods when used in connection with certain plant-food applications.

The plans, treatments and other details of these experiments are given in Table IV, and in Figures 2 and 3 with their following discussions. They include Experiments 217, 218, 219 and 221; parts of Experiments 336 to 339; and Experiment 331 in our experimental orchard at the college. Altogether they contain 1887 trees, 1419 of which are in partial or full bearing and include 11 varieties and 7 soil types.

The results that follow are from 1403 trees, involving 9 varieties and 6 soil types, and cover either 3 or 4 years according to the experiment or phase concerned. The total amount of fruit, covered in the following data and produced during the periods considered, is 606,959 pounds or somewhat over 12,139 bushels. The data from this fruit give us information on 12 different combinations of cultural methods and plant food applications, the combinations being indicated in Figure 2 and in the various tables that follow. The physical basis for these tables and conclusions therefore is somewhat larger in every way than that for our fertilization tables given above.

The influence of cultural methods alone,—without any fertilization,—upon yield, color, size and growth is indicated in the following Tables, XXXV to XXXVII.

Table XXXV.—EFFECT OF CULTURAL METHODS ON YIELD, COLOR, SIZE AND GROWTH, WITHOUT FERTILIZATION.

Expts, 217, 218, 219, Young Orchards.	Plot 1. Clean tillage.	Plot 4. Tillage and cover crop.	Plot 7. Sod mulch.	Plot 10. Sod.
Yield, 1910, -----	8,610 lb	12,129 lb	22,018 lb	18,011 lb
Yield, 1907-10, -----	23,658 lb	28,186 lb	39,794 lb	31,891 lb
Ratio, 1907-10, -----	100	119.1	168.2	134.8
Ratio, 1907-10, -----		100	141.2	113.1
Ratio, 1907-10, -----			124.7	100
Color, % Apples colored $\frac{1}{2}$ or more.				
Color, average % 1910, -----	75.35	68.6	82.9	85.
Color, average 1909-10, -----	75.38	74.8	82.2	85.3
Ratio, 1909-10, -----	100.8	100.	109.9	114.04
Size, average weight of apples in ounces.				
Average weight, 1910, -----	4.35	4.37	4.82	4.22
Average weight, 1908-10, -----	4.45	4.62	4.88	4.53
Ratio, 1908-10, -----	100.	103.5	109.07	101.8
Ratio, 1908-10, -----		100	105.6	
1907-9, Growth, increase in trunk girth, in inches.				
Average increase, 1907-09, -----	4.38	4.14	4.29	3.58
Ratio, -----	122.3	115.6	119.8	100.
Ratio, -----	105.8	100	103.6	

Table XXXVI.—EFFECT OF CULTURAL METHODS ON YIELD, COLOR, SIZE AND GROWTH, WITHOUT FERTILIZATION.

Expts. 336, 338. Age 8 and 22 Yrs.			
	Tillage and cover crop.	Sod mulch.	Sod.
Yield, 1910, -----	18,407 lb	17,937 lb	3,231 lb
Yield, 1908-10, -----	32,119 lb	27,889 lb	22,507 lb
Ratio, 1908-10, -----	142.7	123.9	100
Ratio, 1908-10, -----	115.16	100	-----
Color. % Apples colored $\frac{1}{2}$ or more.			
Color, average % 1909-10, -----	58.6 %	68.2 %	71.9 %
Ratio, -----	100	116.2	122.6
Size. Average weight of apples in ounces.			
Average weight, 1910, -----	5.46—	4.395	4.085
Average weight, 1909-10, -----	4.51	3.92	3.77
Ratio, 1909-10, -----	119.6	103.9	100.
Ratio, 1909-10, -----	115.0	100	-----
Growth. Average increase in trunk girth in inches.			
Average increase, 1908-10, -----	3.60	2.81	2.83
Ratio, -----	128.1	100	100.71
Ratio, -----	127.2	-----	100

Table XXXVII.—EFFECT OF CULTURAL METHODS ON YIELD, COLOR, SIZE AND GROWTH, WITHOUT FERTILIZATION.

Expt. 221. Mature orchards.		Tillage and cover crop.	Sod mulch.
Yield, 1910, -----		25,281 lb	20,496 lb
Yield, 1907-10, -----		59,560 lb	48,791 lb
Ratio, -----		136	100
Color. % apples colored $\frac{1}{2}$ or more.			
Color, average % 1908-10, -----		56.1	79.67
Ratio, -----		100	142
Size. Average weight of apples, in ounces.			
Average weight, 1908-10, -----		4.81	5.33
Ratio, -----		100	110.8
Growth. Increase in trunk girth in inches.			
Average increase, 1907-09, -----		2.9	1.32
Ratio, -----		219.7	100

The methods of obtaining the various kinds of data presented here are the same as those described above in connection with Tables XXVIII to XXXI,—the data on color and size being obtained by the random-sample method and that on yield and growth by weighing the fruit and measuring the trunks of all the trees.¹

In general, it will be observed in the above tables that there are rather marked differences between the various treatments, in nearly every case. In the case of color, these differences are constant in their direction throughout the three tables. They show that so far as color is concerned, sod or sod-mulch has constantly excelled tillage and cover crop by from 10 to 42 per cent. This influence is probably indirect, and it is to be considered as largely or wholly due to the hastening of maturity, as indicated later.

In the other phases covered here, viz., yield, average size of fruit, and growth of tree, there is some crossing in the direction of the differences. For example in the mature orchard of Table XXXVII, the tillage and cover crop system has given double the growth and 36 per cent. greater yield than the mulch system, while in the three young orchards of Table XXXV the latter system has given slightly

¹The height and top-diameters of the trees were also measured, but for various reasons they were found to be less reliable indicators of growth than trunk-girth, and hence were not used in our calculations.

more growth and 41 per cent. greater yield than the former. The results from the two orchards of Table XXXVI in these and other respects are about intermediate between those of the other two tables, as will be observed. This is chiefly because the figures in this table are largely dominated by the greater yields of the older orchards.

The differences observed in the yield and growth of Table XXXVII, as compared with XXXV, indicate that different results are to be expected from these methods in orchards of different degrees of maturity. In other words, the method of soil management that is best for a mature orchard may not be the best for one just coming into bearing, or one in which the bearing habit is not well established.

The mulch system evidently appears at its best in the younger orchards. In them, with the herbage from between the rows and the three-ton-per-acre addition of straw, a very effective mulch of sufficient extent to cover the roots was maintained, while in the old orchard we were unable thus to cover more than probably half the roots. In the latter case, at least the outer half of the roots was under a typical sod and often in dust-dry condition.

In the younger orchards, to which the treatments were applied after bearing age was reached, both the mulch and the sod treatments have undoubtedly exerted a hastening influence on bearing. The increased yields observed on these plots, as compared with those under tillage, are due primarily to more fruits per tree, since the average size of the fruit does not differ materially. This accelerating influence of sod may be seen further in our Table XXXIX, in the sod-and-manure plots especially. These plots, in both young and old orchards, are now leading all others in yield. This sod influence can easily be overdone, however, and made to disappear unless sufficient plant food and moisture is present. This is shown especially by the relatively low yields of the unfertilized sod plots of Table XXXV, as compared with the corresponding mulched plots.

The present evidence, therefore, is fairly clear to the effect that the relative value of the tillage and mulch methods may depend to a considerable extent on the age of the trees to which the methods are applied.

There is also evidence that the character of the soil, especially with reference to its moisture relations, may exercise a very distinct influence upon the results of the two systems. In our opinion, these two facts will largely account for the conflicting results now being obtained in the two experiments of the Geneva Station, in the Auchter and Hitchings orchards; and also for the differences between the results given in Geneva Bulletin 314 and those of Ohio Bulletin 171.

Going back to our own tables, XXXV to XXXVII, we see some interesting differences in effect on size. In the young orchards, besides increasing the yield by 41 per cent., the mulch method has increased the average size of the fruit by about 5½ per cent., as compared with the covercrop method. With the mature orchard, the yield is much decreased, but the average size of the fruit is still greater, the figures for the mulch being—36 per cent. and 10.8 per cent., respectively. In Table XXXVI, however, both yield and average size are diminished by about 15 per cent. in each case. In the two experiments of this table therefore, it is evident that there were about the same number of fruits on the trees, and that the difference

in size is largely or entirely due to differences in moisture conservation, with the advantage here in favor of tillage.

In the young orchard of Table XXXV, however, where the mulch has been applied for four years instead of three, as in XXXVI, and where it covers the root systems more completely, the moisture conservation has apparently been better with it than with the tillage-and-covercrop method. This is indicated by the larger fruit as well as larger crop on these plots.

That this is entirely possible is shown by moisture determinations in mulched and tilled soils made by Shutt,¹ at Ottawa, Canada, in 1905 and 1906. The mulched soils were equal or superior to the others in every case. He also has found that leguminous plants, particularly hairy vetch, are much lighter in their moisture draft than grasses; and that the shade of growing vetch is a better moisture conserver than the mulch formed by cutting and leaving it in place. In other words, the loss by capillarity and evaporation from the practically bare ground was greater at Ottawa than the transpiration through the legume.²

An observation on our Experiment 333, during the current season (1911), confirms this opinion of hairy vetch, but indicates that there is a marked difference in moisture draft between different legumes. In plowing across the plots containing hairy vetch, alsike, crimson clover, mammoth and medium red clovers, the soil was found to be quite dry under the alsike, while it was moderately moist under the mammoth and medium red clovers and very moist under the hairy vetch and crimson clover. This was explainable under the crimson clover on the basis of its having gone to seed and checked its vegetative activities. In the other cases, the wetness of the soil was closely correlated with the degree of pubescence or woolliness of the plants. The smooth and glabrous alsike thus proved to be an active transpirer of moisture, the moderately pubescent clovers gave off water less freely, and the relatively woolly vetch transpired least of all.³ From these considerations, as a permanent cover in orchards, hairy vetch would be best and alsike least valuable of these legumes.

In the case of our young trees above, it is probable that the size of crop per tree was never so great as to bring it into operation in decreasing the size of the fruit. In the mature orchard, however, the latter factor is probably operating. In this orchard also, the mulch has been applied for four years, but it is insufficient as yet to cover satisfactorily the whole root system, so that the conservation of moisture is undoubtedly best under tillage in this case, as shown by soil examinations. It would seem therefore, that, in producing the 36 per cent. increase of yield, the number of fruits per tree had become great enough to react unfavorably upon the size of the individual apples. This relation is discussed more fully later.

The Effect of Adding Manures to the Different Cultural Methods.

In the foregoing tables, we have seen that marked differences appear between the various cultural methods when used alone, i. e., without any extra fertilization. The effect of applying such fertilization is shown below, in Table XXXVIII.

¹Report of the Chemist, Canada Experimental Farms, 1907, p. 151.

²Shutt, F. T. Report of the Chemist, Canada Experimental Farms, 1904, p. 153.

³See article by Wiegand, Karl M. The relation of hairy and cutinized coverings to transpiration. Bot. Gazette 49: 430-444. June 1910.

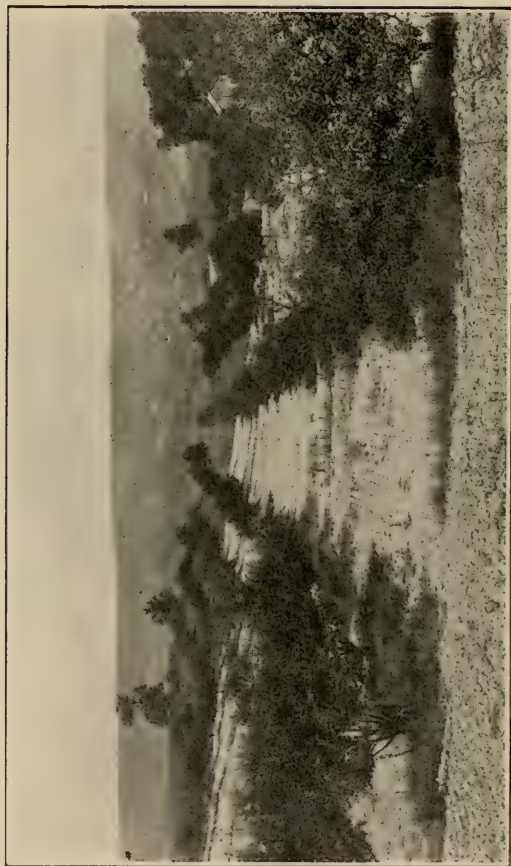


Fig. 14. View of Experiment 219 as a whole.
Looking Westward over the plots from middle of plot 1. September, 1909

Table XXXVIII.—INFLUENCE OF CULTURAL METHODS ON YIELD, WITH FERTILIZATION.

Expts. 217, 218, 219. Young Orchards.	Plots 2 and 3. Clean tillage.	5 and 6. Tillage and cover crop.	8 and 9. Sod mulch.	11 and 12. Sod.
Yields, 1908-9, -----	23,747 lb	21,355 lb	23,774 lb	23,174 lb
Yields, 1910, -----	17,243	19,254	27,740	25,990
Totals, 1908-10, -----	40,990	41,309	51,514	49,164
Ratio, -----	100	100.72	125.7	119.8
Expt. 221. Mature Orchard.				
Yields, 1907-09, -----		41,131 lb	35,946 lb	
Yields, 1910, -----		9,283	28,338	
Totals, 1907-10, -----		50,414	64,284	
Ratio, -----		100	127.5	

As compared with the results in Table XXXV and XXXVII, those in the present table show very marked reductions and one reversal in the differences between methods. For example, differences in Table XXXV of 19, 68, and 34.8 per cent, are reduced here to 0.7, 25.7 and 19.8 per cent., respectively. And in the mature orchard, a difference of 36 per cent. in favor of tillage and cover crops, with no extra fertilization, is converted into an advantage of 27.5 per cent. in favor of mulching when fertilization is added.

The reversal in the latter orchard may be largely accounted for by the practical absence of a crop in 1910 on the plots that received both tillage and fertilizers. This fact, coupled with a remarkable case of *consecutive increase in yield*, which has occurred on the adjacent fertilized and mulched plots, is directly responsible for the observed reversal of advantage between methods. The crop reduction in the former plots was to be expected on account of the very heavy yield the year before. But the steady annual improvement in the yields of the latter was very unusual and unexpected.

The record made by these mulched trees, part of which also received manure and part commercial fertilizer, is as follows: In 1907, they produced 3,050 lb. of fruit; in 1908, 10,351 lb.; in 1909, 22,545 lb.; and in 1910 they produced 28,338 lb. And this increase occurred on mature trees that were receiving no tillage. It is hardly possible for this series not to be broken in 1911, although we are informed that there is again a satisfactory amount of bloom on these trees.

Just why the steady and increased bearing should occur on these plots, 8 and 9, while a decided biennial habit should develop on

the adjacent ones, 5 and 6, which differ only in their cultural methods, we are unable to say as yet. As will be seen by the previous treatment¹ of this orchard, these trees were not unaccustomed to tillage, so that the unsteadiness of bearing in the tilled plots can not be attributed to the strangeness of the treatment. It is possible that the undisturbed development of roots in the mulched plots, together with fair moisture conservation and abundance of plant food, may be the reason for their steadier bearing, but of this we have no positive proof as yet.

Other cases of at least temporarily overcoming the biennial bearing tendency have occurred in our fertilizer experiments, especially in plot 8 of Experiment 220, and in some of the nitrogen and manure plots of Experiments 216 and 338. In plot 8 of Experiment 220, although it is rather unfavorably located, the trees have uniformly been so fully covered with fruit during the past three years as to require thinning, while the adjacent trees have not been even moderately covered during the period of our experiment.

The *leveling effect* of fertilization, noted above, whereby it tends strongly to reduce or even reverse the differences normally associated with the various cultural methods, is partially shown in the following figures, 14 to 21. We say "partially" because the differences in the greenness of the foliage and in the general health and vigor of the trees are not reproducible in the prints. The differences between the fertilized plots and plots 1, 4, 7, and 10 which are unfertilized, are sufficiently great in most cases, however, to impress even the camera.

These pictures were taken in Experiment 219, partly by the writer in September 1909, and partly by Mr. Hershey in June 1911. Distant views containing more than one plot in the same picture were taken wherever conditions permitted. This, of course, naturally reduced the differences in the pictures, but it gave better opportunity for comparison.

In one case, that of plot IV, the failure to make satisfactory growth is not entirely chargeable to the method, which is tillage and cover-crop without fertilization. The soil in part of this plot is thinner than in the other portions of the experiment and the trees are having more difficulty in getting a good start without the fertilization, which has proved so effective in the other plots.

We have stated above that our cultural method experiment gives data on twelve different combinations of cultural methods and plant food applications. These combinations and their results on yield are given in Table XXXIX.

¹See record of previous treatment in description of soils of experiment 221, following Table IV.

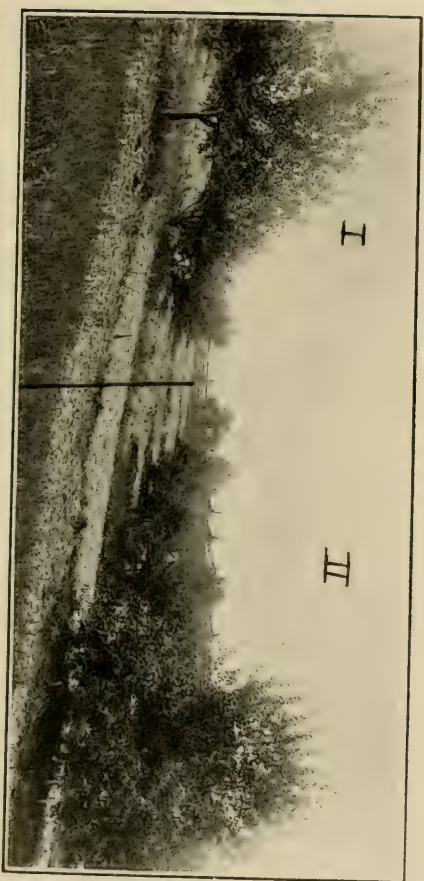


Fig. 15. View Between Plots I and II of Experiment 219.
Note increased size of manured trees in plot II. September, 1909.

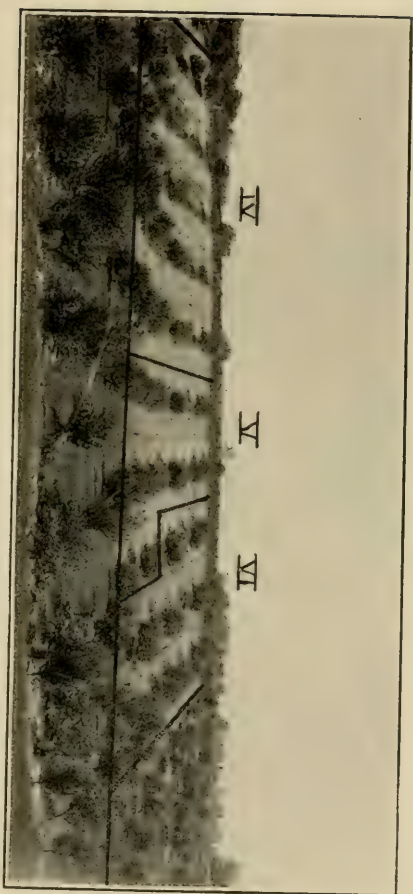


Fig. 16. Distant View of Plots IV, V, and VI, in Experiment 219.
These plots receive tillage and cover crop; IV is unfertilized; V is manured;
VI receives complete commercial fertilizer. Note difference in growth. Also
see page 482. June, 1911.

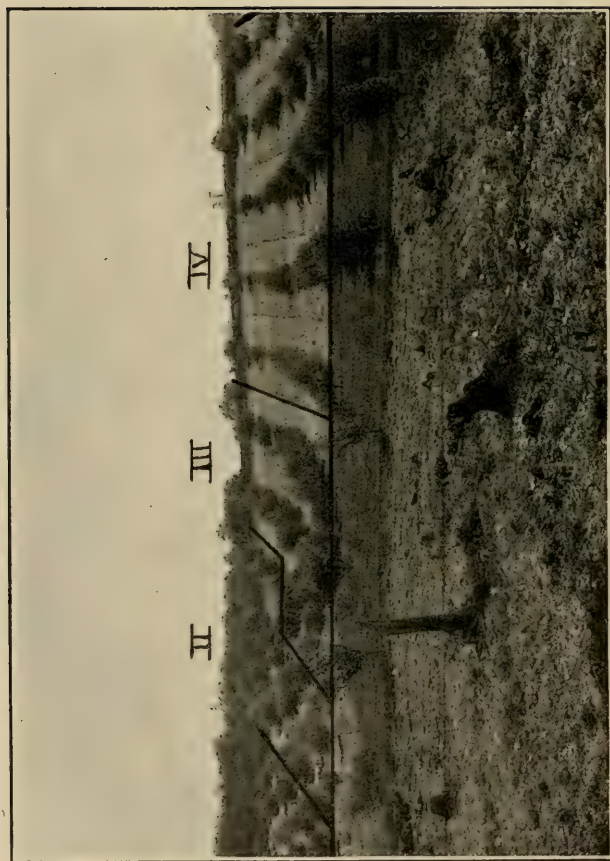


Fig. 17. Distant View of Plots II, III and IV.

The two former plots received clean tillage, with manure and complete commercial fertilizer, respectively. The latter receives tillage and cover crop, with no fertilization. Note difference in growth, and see text below Fig. 21. June, 1911.

Table XXXIX.—EFFECT OF MANURES ON YIELD.

(When Used with Different Cultural Methods.)

Expts. 217, 218, 219. Young Orchards, 1908-10.			
	Unfertilized.	Manure 12 T. per A.	Com. fertilizer, 30-60-100 lb per acre.
Clean tillage, ...	22,309 lb	33,560 lb	40,256 lb
Tillage and cover crop, ...	26,679	33,169	40,493
Sod mulch, ...	37,730	45,727	45,909
Sod, ...	29,719	51,532	34,995
Totals, 1908-10, ...	116,437	163,988	161,053
Ratio, ...	100	140.8	138.3
Ratio, ...		101.8	100
Expt. 221. Mature Orchard. 1907-10.			
Tillage and cover crop, ...	59,550 lb	49,600 lb	47,826 lb
Sod mulch, ...	42,290	65,894	58,496
Totals, 1907-10, ...	101,830	115,494	106,322
Ratio, ...	100	113.4	104.4
Ratio, ...		108.6	100

In general, it will be observed that in every case but one the yields from the fertilized plots have surpassed those from the unfertilized. This one exception is the tilled plot 4 of Experiment 221. The full year for this plot was in 1910, the year in which as stated above, the corresponding tilled-and-fertilized plots of this experiment had practically no fruit. This largely accounts for the present superiority in the total yields of the unfertilized plot 4.

The trees of this plot also are naturally the best in the orchard, and are said to have yielded considerably better than the others before our experiment started. Being close to the house they have doubtless received somewhat more fertilization and other care than the others farther away. And the present system of tillage, with the heavy green manuring that is being furnished by the cover crops, is apparently all that is needed to give good yields. It will be observed, however, that even this plot is now being surpassed by the mulch and manure plot of this experiment.

In total effects, fertilization shows a gain in every case over its absence. In the young orchards this gain is from 38 to 40 per cent. In the mature orchard, the gains are now smaller, owing chiefly to the biennial bearing that has developed in the tilled plots, as indicated above. The full crop of the past year was on the unfertilized plot with very light crops on those receiving fertilization, and another year's crop is required to give both plots the same number of full and off years, since the habit became apparent.

In the relative effect of manure and the commercial fertilizer used in these experiments, there is not much difference. The total superiority of the manure runs from about 2 to 8½ per cent., although, as stated in our treatment description, much more actual plant food is being applied in it and at a greater cost. It should be remembered however, that the fertilizer used here is a "complete" one, i. e., it carries nitrogen as well as the mineral elements. In many discussions of commercial fertilizers in their relation to fruits, the term has apparently been restricted to the mineral elements only. Also in a number of experiments, the nitrogen element has been omitted entirely, a fact which doubtless has had much to do with the lack of results.

In connection with the different cultural methods, it will be observed that the plots receiving manure in combination with sod or sod-mulch are now leading all others in both divisions of Table XXXIX. Also manure in conjunction with tillage is now slightly in the lead in the mature orchard. This condition is reversed, however, in the younger orchards, by about 20 per cent. in both tillage methods. It is not yet clear whether or not this fact has any real significance. At any rate, the data show that either material may be used satisfactorily with either cultural method, when the orchards are not being limited by other conditions.

Influence of Manures Upon Other Crop Phases.—The influence of the above manurial applications upon color, average size of fruit, and tree growth is shown in Table XL.

Table XL.—EFFECT OF MANURES ON COLOR, SIZE AND GROWTH.

A. Expts., 217, 218, 219. (a) Color. % Apples colored $\frac{3}{4}$ or more.

	Unfertilized.	Manure.	Commercial fertilizer.
Color, average % 1908-10, -----	73.5	63.1	64.7
% benefit, -----	100	-10.36	-8.8
Ratio, -----		85.85	88.03

(b) Size. Average weight of apples in ounces.

Average weight, 1908-10, -----	4.19	4.53	4.52
Ratio, -----	100	108.1	107.9

(c) Growth. Increase in trunk girth, in inches.

Average increase, 1907-09, -----	4.12	4.3	4.43
Ratio, -----	100	104.1	107.5
Ratio, -----		100	103

B. Expt. 221. (a) Color. % apples colored $\frac{3}{4}$ or more.

Color, average % 1908-10, -----	67.9	65.5	66.2
% benefit, -----	100	-2.4	-1.7
Ratio, -----		96.47	97.5

(b) Size. Average weight of apples in ounces.

Average weight, 1908-10, -----	5.07	5.65	5.42
Ratio, -----	100	111.4	106.9

(c) Growth. Average increase in trunk girth in inches.

Average increase, 1907-09, -----	4.22	5.86	4.92
Ratio, -----	100	139.0	116.6
Ratio, -----		110.1	100

As shown in this table, the effect of manures on the phases considered has been fairly distinct in both old and young orchards. Their usual effect of reducing color is apparent here, just as it was in our fertilization experiments above. The reduction in this case is less with the commercial fertilizer, doubtless on account of its smaller nitrogen content, thus causing relatively less delay in maturity.

There has been some increase in size of apples and in wood-growth following the fertilization. The increase is somewhat greater with the manure, in all cases, except that of growth in the young orchards, where the fertilizer has shown slight superiority. This may be connected with the smaller area over which it is distributed, thus giving relatively stronger applications; but the difference is hardly great enough to warrant definite consideration.

The increase in size of fruit is probably again rendered possible here, because the accompanying increase in yield has not been great enough to bring in the reducing influence of extra crop size. In support of this view it may be noted that the increase in size is somewhat greater on the mature orchard, where the accompanying increase in yield has been less.

Some General Remarks on Certain Methods.—From what has been seen above, it is evident that there is no one best cultural method for all situations. It is doubtless true that for the mature orchard, where the tillage-and-covercrop method is available, it is generally to be preferred, using tillage at least as often as every other year. The same statement probably holds for the young orchard until bearing age is approached. This is apparently true so far as the influence of the method itself is concerned.

When used in conjunction with fertilization, the evidence at present is not so clear. This is because of the remarkable and regular increase in bearing that has taken place in the mulched and fertilized plots of Experiment 221. If this continues, it will indicate that the yearly root pruning occasioned by tillage is of more consequence than has been supposed. For various reasons, we are beginning to look with less favor upon the heavy pruning of tree tops,¹ and it is quite possible that something of the same attitude will develop in connection with root pruning, such as occurs in the ordinary methods of tillage.

Where tillage is impracticable, however, as is the case in many good orchard locations, and sometimes where it is available, the mulch method may often have much to commend it, as indicated in our results. Without attempting to champion it or any other single method, we may sum up the situation in regard to proper mulching as follows. It avoids erosion on sloping ground; reduces labor; avoids the root-injury due to cultivation; increases color; enhances the value of the fallen fruit; apparently hastens bearing in young trees; may assist in blight control; and effectively conserves moisture, if the mulch is maintained sufficiently deep, which means three or four inches at least. Its defects are: frequent high cost of sufficient materials for effective mulch; probable reduction in yields in mature orchards, unless accompanied by sufficient and proper fertilization; possible danger from mice and from fire; favorable hibernating quarters for injurious insects and fungi; and lack of flexibility in moisture control, the moisture being conserved as thoroughly in late fall, when not often wanted, as it is at any other time. Its successful use, therefore, is likely to depend on age of trees, local conditions, prevailing pests, relative cost of labor and of mulch materials and the general moisture conditions of the orchard in which it is used.

¹See Report of Woburn Experimental Fruit Farm for 1907, for example. In this report it is shown that all pruning, regardless of season, tends to delay fruiting and reduces both yield and growth, the reduction being approximately in proportion to the severity of the pruning.



Fig. 18. Distant View of Plots V, VI and VII, of Experiment 219.
 See Fig. 17 for treatment of V and VI; VII is mulched with no fertilization.
 The latter trees are growing nearly as well as the former in this case, but the
 foliage was better on former. September, 1909.

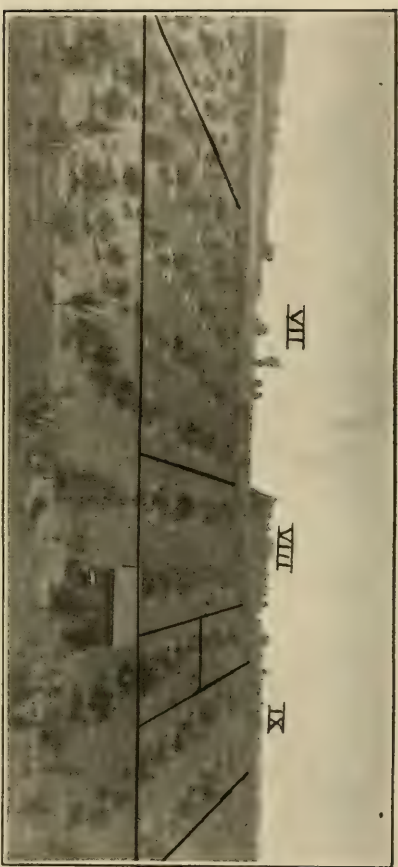


Fig. 19. Distant View of Plots VII, VIII and IX, of Experiment 219. These plots receive the sod-mulch treatment. VII is unfertilized; VIII is manured; and IX receives complete commercial fertilizer. The growth is a little greater on the latter plots and the foliage and general appearance of the trees is distinctly better in the latter cases. September, 1909.

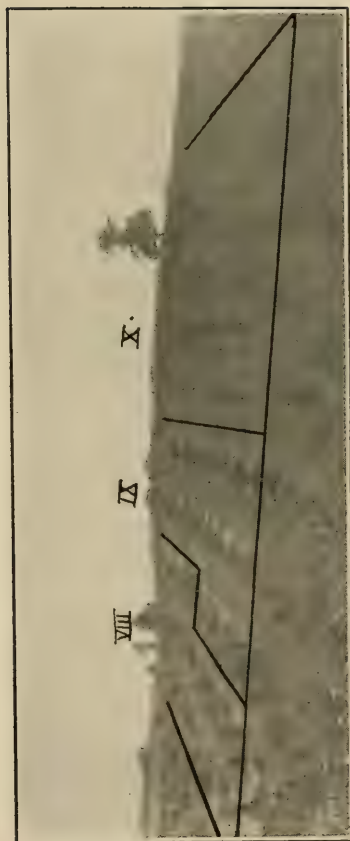


Fig. 20. Distant View of Plots VIII, IX and X, of Experiment 219.
See Fig. 19 for treatments of VIII and IX, Plot X is in sod with no fertilization.
Note great superiority of former plots. The soil of X is newer than that of the
preceding plots in this experiment, and should be better. September, 1909.

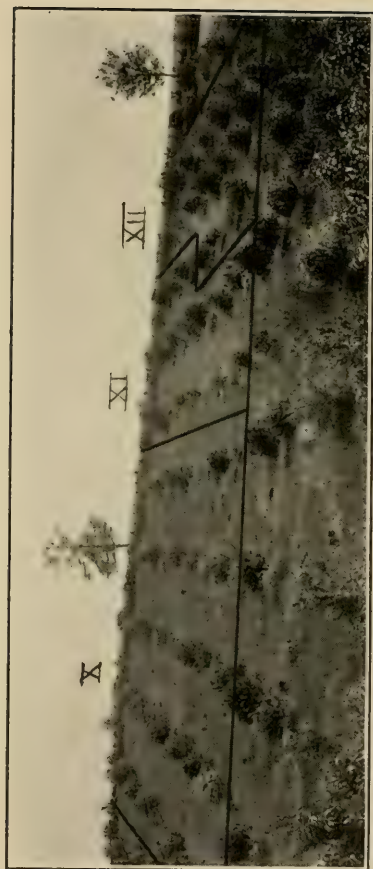


Fig. 21. Distant View of Plots X, XI and XII, of Experiment 219. These plots receive the sod treatment. X is unfertilized; XI is manured; and XII receives complete commercial fertilizer. While it is not brought out well in the picture, the growth is much better in the two latter plots, as is also the case with their foliage and general appearance. June, 1911.

Distribution of Feeding Roots in Apple Trees.

This is a question that is of interest both in the application of fertilizers and the use of cultural methods. It has received some attention in various places, of which we may cite the Experiment Stations in Wisconsin,¹ Illinois,² Arizona,³ and Ohio,⁴ and the Woburn Experimental Fruit Farm in England.

The greatest depths of roots observed at the various places are as follows: Wisconsin, 9 feet; Illinois, 5 feet; and Arizona, 20 feet, in the case of an irrigated peach root. In Ohio, the roots apparently were examined only to a depth of one foot, but it is stated that in all cases studied most of the feeding roots were removed in the first six inches of soil.

In order to get more evidence on this question, especially with reference to the particular conditions existing in our own experiments, in 1908 we made some studies of the root distribution, both horizontal and vertical, in each of 28 apple trees. The results are shown in the following Table XLI.

Table XLI.—ROOT DISTRIBUTION IN APPLE TREES.

(As observed in the Pennsylvania Apple Experiments in 1908.)

Expt.	Variety.	Age in 1908.	Root Length Ft.	Vertical Range of Feeding Roots.	
				Range of depth Observed. In.	Zone of Maxi- mum Numbers. In.
216,.....	Jonathan, ----	9	13.5	1 to 12	2 to 7
216,.....	York Imper., --	9	11.	1 to 12	1.5 to 7
217,.....	York, ...	15	10.75	1 to 25	2 to 17
217,.....	Gano, ...	15	18.75	1 to 20	2 to 8
217,.....	York, ...	15	16	1 to 18	2 to 10
217,.....	Gano, ...	15	12.5	1 to 24	2 to 16
218,.....	Albemarle, ----	13	18	1 to 33	1 to 21
218,.....	York, ...	9	10.2	1 to 26	4 to 15
218,.....	Albemarle, ----	13	5.75	1 to 24	3 to 15
218,.....	York, ...	9	15.25	1 to 16	5 to 12
219,.....	Jonathan, ----	6	10.5	1 to 20	2 to 10
219,.....	York, ...	6	11.25	1 to 19	2 to 11
219,.....	Jonathan, ----	6	11	1 to 19	3 to 13
219,.....	York, ...	6	9.75	1 to 20	5 to 15
220,.....	Baldwin, ...	10	27	1 to 18	6 to 14
220,.....	York, ...	20	19.75	1 to 24	1 to 8
221,.....	Baldwin, ...	36	39	2 to 24	5 to 14
221,.....	Baldwin, ...	36	30	1 to 22	4 to 15
221,.....	Northern Spy, --	36	36.5	1 to 20	3 to 12
221,.....	Northern Spy, --	36	45.5	1 to 36	4 to 14
336,.....	Grimes, ...	8	14	1 to 32	2 to 11
336,.....	Smokehouse, ---	8	13.5	2 to 15	3 to 10
336,.....	Stayman, ...	6	14.5	1 to 18	2 to 9
338,.....	Baldwin, ...	20	21.5	1 to 42	2 to 12
338,.....	Baldwin, ...	20	27.75	0 to 20	3 to 10
338,.....	Baldwin, ...	20	36.5	0 to 21	.5 to 10
339,.....	Baldwin, ...	14	28.25	1.5 to 18	2 to 11
339,.....	Fallawater, ---	14	25.75	1 to 23	2 to 11
Averages,--	(28 trees), ----	15	19.77	1.07 to 22.16	2.7 to 12.0

¹Goff, E. S. A Study of the Roots of Perennial Plants. Wis. Rpt. 1897, pp. 286-98.²Burrill and Blair. Effect of Cultivation on Root Systems. Ill. Bul. 52: 109-10, 1898.³McClatchie, A. J. Arizona Station Rpt. 1899, pp. 257-59.⁴Green and Ballou. Ohio Bulletin 171.

The general character of the soil in each of these experiments is stated in Table IV and its following discussion. Since the study was rather of a preliminary nature, relatively simple methods were used, as follows.

In getting at the root length, trenches were started, about in the center of the square formed by four trees, and continued until a root of some size was found. This root was then followed until its tip was approximately reached, and the total distance from the parent tree was determined. This of course did not always locate the really longest roots, but it gave information upon the roots that were among the longest of those originating from the four trees forming the square.

In determining the vertical distribution, trenches were dug at right angles to a line of emergence of the roots and about midway between the trunk and the tips of the branches. These trenches showed the depths of the roots coming from that side of the tree, and they were continued downwards until further appearance of roots apparently ceased.

From the results in Table XLI, it will be seen that the maximum root-length observed was $45\frac{1}{2}$ feet. This was in a Northern Spy tree of Experiment 221. The maximum depth observed was 42 inches in a Baldwin of Experiment 338. The general depth of maximum numbers of feeding roots ranged from 2.7 inches to 12 inches, on the average, with extremes of 0 to 21 inches.

It will thus be seen that the root-feeding zone is relatively shallow in apple trees, at least under many eastern conditions, where the soil moisture is usually fairly abundant until the surface is nearly reached. In more arid conditions, such as are found in Arizona, however, the roots may go downward to very considerable depths. The direction of growth in apple roots is therefore evidently governed largely by moisture supply, as is the case with other plants.

Hence the cultural method that conserves moisture best will probably tend to *reduce* the depth of roots, rather than increase it, so far as the direct influence of the method itself is concerned. The danger of excessive root-pruning by plowing deeper than 4 or 5 inches over apple roots, under normal conditions, is also very apparent. In some cases the trees seem able to stand it, but we believe that there is opportunity for caution and improvement in this regard.

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VARIATION AND HEREDITY AS FACTORS IN APPLE PRODUCTION.

This is a phase of our subject that has received comparatively little definite and continuous attention in the past, though it has been referred to many times and it is now receiving attention in a number of places. Of these may be noted the Canada Central Experimental Farm at Ottawa, the Experiment Stations of: New York (Geneva), Maryland, Virginia, Illinois, Iowa, Indiana, Missouri, Arkansas, Kansas, Wisconsin, Minnesota, North Dakota, South Dakota, Nebraska, Idaho, Oregon, and our present experiments at the Pennsylvania Station.¹ Besides this, in a very few cases, systematic work is also being done by private individuals.

If improvement is possible in apples or other fruits through the means of variation and heredity, we can see no good reason why it should not become extremely important. These forces of variation and heredity are being utilized in the improvement of other crops; and why this should not also be possible in apples is not entirely clear.

The difficulties in the way are essentially two. First, if the effort toward systematic improvement is made by the way of the seed, we are confronted by the extremely heterozygous condition of the gametes. This has resulted from repeated cross-pollination for centuries, and is indicated in the well known conspicuous failure of most fruits to come true to seed. It therefore seems necessary to devote much time to a study of the gametic characters of a given variety, and possibly to reduce their number, before any considerable, systematic progress can be made by way of the seed.

On the other hand, if the effort toward improvement is made by way of cion-selection, we find ourselves dealing with so-called "pure lines" or biotypes, in which we are informed that no important progress by selection is possible.

Despite these facts and apparently well-established principles, we are giving some attention to the second possible method of improving apple production, viz., by cion-selection. This phase of the problem naturally divides itself into two questions. First, do important variations occur between trees or parts of trees of the same variety? And second, if they do occur, are they heritable; i. e., are they due to internal or to external causes?

THE EXISTENCE OF IMPORTANT VARIATIONS IN APPLES.

In answer to the first question, with reference to yield especially, we have brought together and compared a considerable amount of data from our own experiments and those of others. These data were originally obtained, in all cases, in connection with other kinds of experiments, but by *comparing only the yields of trees that were under apparently identical conditions*, we have assembled the data shown in the following Tables, XLII to XLV.

¹For the general character of the work at each of these places, see article by S. A. Beach on "The Present Status of Apple Breeding in America," in American Breeders' Association Rpt. for 1909, pp. 28-36.

*Table XLII.—INDIVIDUALITY IN BEARING OF APPLE TREES.
(NEW YORK).*

(Yields for 10 years and relative position of 6 trees in 1896 and during the 10-year period.)

Tree.	Yield, 10 yr., bu.	Ratio.	Percentage of Total Yield.			
			1896.	Rank.	10-year Period	Rank.
No. 1, -----	72.25	-----	12 %	2	13 %	2
2, -----	125.50	-----	21.2	6	22.6	6
3, -----	85.58	-----	15	4	15.4	4
4, -----	64.98	-----	11	1	12	1
5, -----	84.58	-----	17	3	15.2	3
6, -----	121.0	-----	20.8	5	21.8	5
2 & 6, -----	246.5	179.6	-----	-----	-----	-----
1 & 4, -----	137.2	100	-----	-----	-----	-----

Table prepared from data given by S. A. Beach in Geneva Bulletin 239: 218-19, 1903. The variety was Rhode Island Greening.

Table XLIII.—INDIVIDUALITY IN BEARING OF APPLE TREES. (CANADA).

(Comparative yields in gallons, for 14 years of single trees in each variety.)

Variety.	Tree.	Age 1908.	Yields.	Ratio.
Wealthy, ² -----	No. 4	13	154.25	263
Wealthy, ² -----	8	13	58.5	100
MaMahon, -----	1	11	753.5	462
MaMahon, -----	2	11	579.5	355
MaMahon, -----	7	11	163.5	100
McIntosh, -----	1	19	501.5	218
McIntosh, -----	2	19	250.5	100
Patten, -----	1	17	502.5	240
Patten, -----	13	17	209.5	100
Average, 4 high trees, -----	-----	-----	477.94	288
Average, 4 low trees, -----	-----	-----	165.5	100

1. This table is prepared from data given by W. T. Macoun in Canada Experimental Farms Rpts. for 1905 to 1908. Yields are stated in gallons in all cases

2. Yields are for 10 years only, in this case.

Table XLIV.—INDIVIDUALITY IN BEARING OF APPLE TREES. (MAINE).

(Comparative yields of 10 highest and 10 lowest trees under similar conditions during 5 years.)¹

Variety.	High Yielders.		Low Yielders.	
	Tree.	Total Yield.	Tree.	Total Yield.
Baldwin, -----	No. 25	22.3 bbl.	No. 24	6.5 bbl.
"-----	42	13.1	43	4.8
"-----	51	16.3	52	4.7
"-----	81	14	74	4.4
"-----	17	13.5	18	1.8
"-----	20	17.9	26	3.3
"-----	47	17.4	50	3.8
"-----	88	14.9	89	2.2
"-----	31	13.5	61	3.1
"-----	32	15	99	3.4
Totals, -----	10	157.9 bbl.	10	38.0 bbl.
Ratio, -----		415.5		100

¹. Prepared from data given by Munson in Maine Station Bulletins 122; 193-5; 139; 56; 155; 134 and 137-38. 1905 to 1908. The trees averaged about 40 years old at the close, 1907.

Table XLV.—INDIVIDUALITY IN BEARING OF APPLE TREES. (PENNSYLVANIA).

(Comparative yields of 10 highest and 10 lowest yielding trees, under similar conditions, in each of 20 cases involving 11 varieties, during three years.)

Expt. No.	Variety.	High yielders.	Low yielders.	Excess.	Excess per acre.	Ratio to 1.
		lb.	lb.	lb.	bu ¹ .	
215	Stayman Winesap, -----	605.83	59	606.83	42.48	11.28
215	York Imperial, -----	1138.75	164.25	974.5	68.21	6.932
216	Jonathan, -----	6279.	1685.5	4593.5	321.54	3.725
216	York, -----	7142.5	1640	5502.5	385.17	4.355
217	York, -----	14667.75	1852.	12815.75	897.1	7.919
217	Gano, -----	11752.75	1614.5	10138.25	709.67	7.28
218	Albemarle, -----	4626.75	137.	4489.75	314.28	33.76
218	York, -----	2781.75	129.5	2662.25	182.15	21.08
219	York, -----	880.5	16.25	814.25	57.—	51.11
219	Jonathan, -----	1539	247.25	1291.75	90.42	6.224
219	Ben Davis & Gano, -----	1115.	85	1030	72.1	13.12
220	York, -----	9798.5	4365.5	5433	380.3	2.244
221	Baldwin, -----	26671.75	6410.	20261.75	1418.32	4.16
221	N. Spy, -----	31315	11453	19856.5	1389.95	2.733
336	Grimes, -----	1557.5	122	1435.5	100.48	12.76
336	Smokehouse, -----	2413.5	335.5	2078	145.46	7.194
336	Stayman, -----	1209	2	1207	84.49	(604.5)
388	Baldwin, -----	13439.5	3507.	9935.5	495.44	3.832
339	Baldwin, -----	4123.75	626	3497.75	244.84	6.587
339	Fallawater, -----	2333.5	137	2196.5	153.75	17.03
Average (20 cases, 11 varieties), -----		7267.5	1729.6	5538.0	377.65	11.754

¹. This computation is based upon an acre of 35 trees, and 50 pounds of fruit per bushel. The actual number of trees per acre was greater in most cases.

From these tables it is quite evident that very marked variations in bearing do exist among apple trees, even though they be of the same age, of the same variety, in the same orchard and apparently under identical treatments. Thus in Table XLII, during 10 years, two Rhode Island Greening trees produced over one and three-quarters times as much fruit as two others adjacent and under the same respective treatments. Among the six trees of this table also, the difference in productiveness seemed to be a rather permanent character of the individual tree since they retained practically the same relative productiveness throughout the 10-year period as they had in 1896, the fourth year.

In Table XLIII, during 11 years, four trees have averaged nearly one and two-thirds times as much fruit as four others, with individual contrasts as high as 4.6 to 1. In Table XLIV, during 5 years, ten Baldwin trees produced over four times as much fruit as ten others adjacent and similarly treated, with individual contrasts as high as $7\frac{1}{2}$ to 1.

In Table XLV, the ten highest yielding trees in each of 20 different cases, have averaged $4\frac{1}{3}$ times as much fruit as the ten lowest trees in the same varieties, with individual 10-tree contrasts running as high as 50 to 1.¹ Some of these higher differences are attributable to the youth of the trees, young trees being always more or less erratic in their bearing.

In general, however, the average differences indicate an indisputable tendency to greater yields in some trees than others. It will be observed that in the trees of our experiments, although some of the yields are comparatively light, this difference has amounted to 377.65 bushels per acre during the 3-year period, or about 128 bushels per acre per year,— a gain which is obtained practically without cost.

Nature of These Variations, and Present Evidence on Their Inheritability.

It seems hardly possible that all the differences observed here are due to environmental influences. In the large number of trees considered it would seem that at least some of them are higher yielders because of inherent or internal variations in this respect. As we shall see later, unquestioned vegetative variations in other respects, such as color and season of fruit, color of foliage, and habit of growth, have occurred among horticultural plants, a number of which have been fairly steady in their propagation. Variations in yield can hardly be essentially different from those of color. The problem, therefore, is to isolate the *inherent high yielders* from the groups of trees that have been definitely shown to be relatively high producers during a series of years.

This of course can only be done by propagative trials, which brings us to the second of our questions stated above. Upon this phase, we have very little positive evidence to offer, so far as yield is concerned, though there is considerable negative evidence available.

We are now testing this inheritance phase fairly extensively, by comparing ordinary nursery trees with other trees planted at the same time and topworked with cions said to be from superior trees.

¹In one case, in experiment 336, a contrast of 604 to one is shown. But this is clearly due to the youth of the trees, (ages shown in Table IV), and this relative yield is not included in determining the final average rates.

We had no data such as that given in Tables XLII to XLV, when this test was started, so that in nearly all cases we have had to rely upon the general observations of practical orchardists for evidence of superiority. Thus whenever we have learned of a specially noted individual tree, we have obtained cions from it, if possible, and worked them into our test. We now have under trial some 49 possible strains of 25 varieties obtained in this manner. This is to be supplemented by tests of cions from high and low yielding trees of more definite previous history as opportunity permits.

The evidence available elsewhere upon the heritability of superior characters in apples is very largely negative. Notes on the results of trials have been kindly furnished us in letters from a number of persons, as noted below. The essential portions of these letters are as follows:

(1). Abstract from letter of Dr. J. C. Whitten, Missouri Experiment Station, March 1910.

"Fifteen years ago I began taking observations and measure of the crop from the most productive and the less productive trees in a Ben Davis orchard on the Experiment station grounds here. At the end of three seasons, I took scions from the Ben Davis tree which for a period of three years proved to be the best producer year after year, and also from the Ben Davis tree in the same orchard which was the poorest producer for the period of three years. Of course, we eliminated from consideration trees that were undersized, broken, diseased, or from any other environmental influence in the orchard, made it evident that their productiveness or unproductiveness was due to external conditions rather than to any possible inherent qualities of the trees themselves.

"This past summer we secured the first full crop of fruit which has yet been borne upon these trees, they having fruited only very sparingly here and there in previous seasons. We have found no difference whatever in the productiveness of the trees propagated from the good producer and those propagated from the poor producing tree. The quality, size and quantity of the fruit is equally as good on those trees propagated from the poor producing Ben Davis. In planting these trees out in the orchard we have alternated a good producer and a poor producer in the rows so as to make their environmental conditions as near alike as we possibly could. From this one experiment, of course, I do not mean to conclude that there is nothing in scion selection. Of course, the poor producing apple tree may have been a poor producer because of some environmental condition which we could not see. The good producer likewise may have had some favored condition of environment which was not visible to us. It seems to indicate, however, that one cannot be sure every time that a good producing tree is out-fruited by its fellows because of inherent qualities alone. Or else if it has these inherent qualities, it might not always be capable of producing them into budded offspring."

(2). Abstract from letters of Joe A. Burton, Mitchell, Ind., March 1909, and February 1911.

"I have been trying to improve apples by selection in the Indiana Experimental orchard for several years. First, I asked if the stock worked any change on the cion. Yellow Transparent was grafted into a wild crab. Leaves of the Transparent were removed later, so that apple had to grow on sap prepared by crab leaves alone. Result, perfect Yellow Transparent fruit.

2. "Deep red Ben Davis grafted into light colored Ben Davis. Fruit from grafts all light colored.

3. "Small poor-quality Rambo grafted on same stock with high-quality Rambo. Result, both good alike.

4. "Little green Genet (Ralls) on tree with large red Genet. Apples all the same.

5. "Ben Davis, Jonathan and Grimes cions from nursery rows,—the two former having been re-propagated thus, for over 40 years,—were grafted on same stock with cions from good bearing tree. All bore alike.

6. "Grimes from a regular annual bearer with cions from two very shy bearers. All fruit alike.

7. "Water sprouts from Benoni and Yellow Transparent grafted on same stock with cions from bearing wood. All bore alike.

8. "Warfield Strawberries grown and selected for 12 years by the late R. M. Kellogg, were planted in alternate rows with Warfield from our own patch that had been propagated from tips only, for the same time. Result, no one could see any difference."

(3). Abstract from letter of L. L. Springer, Edenville, Pa., May 1911.

"A number of years ago, one Salway peach tree appeared among four rows of trees in one of my orchards that was far superior to all others. It bore annually, the fruit was larger, more highly colored and better in every respect. I propagated from this tree for three years, when I found to my great disappointment that there was no improvement over other Salway trees.

"This tree stood on a little knoll perhaps 18 to 20 inches higher than the surrounding ground. Hay and grain did not grow on this elevation and I had supposed it be too hard and poor to grow anything. And yet the difference seems to have been in the soil."

(4). Abstract from letter of Herbert P. King, Trumansburg, N. Y., May 1911.

"Some years ago we noticed one limb of an Elberta peach tree that ripened its fruit about 10 days earlier than the others. After noting this for three years, we budded a few trees from this limb, and their first fruit appeared last year. It ripened all the way from two weeks ahead of ordinary Elberta to the same time as the latter. We have now budded a second time from the earliest ripening limbs, hoping to fix the quality of early ripening."

(5). In an article by W. J. Wright, of The Pennsylvania State College, in the *Rural New Yorker*, 1911: 155, Mr. J. W. Kerr of Maryland is quoted as follows:

"A test, with trees propagated from a tree of Wild Goose plum that produced fruit notably large and fine as compared with trees propagated from the other extreme, demonstrated clearly that, under like conditions of soil, both were average Wild Goose plums. No more, no less."

It will be seen from the above communications that rather scant evidence of the value of selecting cions from trees with superior or desirable qualities, is available as yet. In fact the "pure line" or biotype exponents seem to have the best of the argument thus far.

It is not yet finally proved, however, that selection does not have value for the purposes indicated. This negative evidence is valuable in showing that the size of the problem is greater than is generally supposed. But there are some inklings of final success, in the peach work by King for example, and especially in some of the apparently heritable variations in color referred to below.

The principles involved do not differ materially from those of nurserymen in discovering and propagating new vegetative types of ornamentals and other plants. For this reason, we have observed operations in a number of nurseries, and the following statement from the experience of the Hoopes Brothers & Thomas Company, of Westchester, Pa., is representative.

"We are constantly finding, among trees and shrubs, sports that are different in character from the original tree, either variegated leaves or different colored leaves or different forms of growth. A few of these like the Rivers Purple Beech, Schwedleri Maple, etc., have become fixed and do not change, but most of the others are liable to go back to the original form; for instance, the Tom Thumb Arbor Vitae is one of the best examples. It is a variety of the American and the growth is entirely distinct. Unless you are familiar with it, you would not think it was an Arbor Vitae, and yet generally in a few years it goes back to the original species. The variegated Privet is another sample of these sports. It holds its variegation for a few years, and gradually you will find a shoot coming up green which increases each year until the variegation has disappeared."

It is not unlikely that some of these conditions will be found to obtain in the vegetative variations of apples and other fruits.

Incidentally, however, the indicated behavior of Privet, so far as albino variegation in foliage is concerned, is apparently explainable. The particular phase of environment or nutrition concerned in this and similar cases is probably calcium supply. As brought out in connection with our discussion of mineral nutrients, on page 453 one of the things found in certain analyses of foliage is that albino leaves contain much less calcium than normally green ones, the reduction often being to less than half the lime content of the latter.

This suggests the connection stated above, that albino leaves are to be attributed to lack of calcium, the lack arising either as a result of its actual deficiency in the soil or as a result of defects in the nutrition of the plant showing the variegation. In corroboration of this view, the following experience of J. P. Pillsbury, while in charge of the landscape work at this Station, is of interest.

About 1896, it was decided to change some 15 plants of a variegated form of *Sedum telephoides* from a border planting to another situation about 75 feet distant. These plants had always shown markedly variegated leaves and stems of the albino type, and the most variegated plants were chosen. The soil in the new situation was of a stiffer clay than in the previous border, and therefore was limed heavily to improve its texture.

As a result, the transferred plants within a year or two lost all traces of their previous variegation and so far as observed they have maintained a deep green foliage and vigorous growth until the current season, 1911. During this season, a few plants near the middle of the border are again showing traces of variegation. No lime has been applied to the plot since the original application, 15 years ago.

While this has only an incidental bearing on our particular problem, yet it shows the possibility of more definitely isolating the particular environmental features that are at present clouding some of our results.

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FACTORS INFLUENCING SIZE IN APPLES.

We have seen above that, under certain conditions at least, the size of apples can be influenced by fertilization and also by cultural methods. Their average size is also evidently influenced by inherent or internal causes, as shown by the differences in size between varieties, and also probably by some of the differences between individual trees of the same variety.

But we have also noted cases in which none of these factors had their usual effect. In these cases, other factors evidently cut across the results, and exerted the dominant influence. Among the latter influences, the size of the crop on the tree in proportion to the available moisture supply, or in other words, the amount of moisture available per individual fruit, has seemed to be the most potent. On this account and also because of its relation to the value of thinning, we have given some special attention to the latter factor.

Considerable data on this,—some of it merely eliminating other factors,—is given in our tables above. In the present space, we shall confine our attention to data obtained in connection with an orchard

TOMPKINS KING

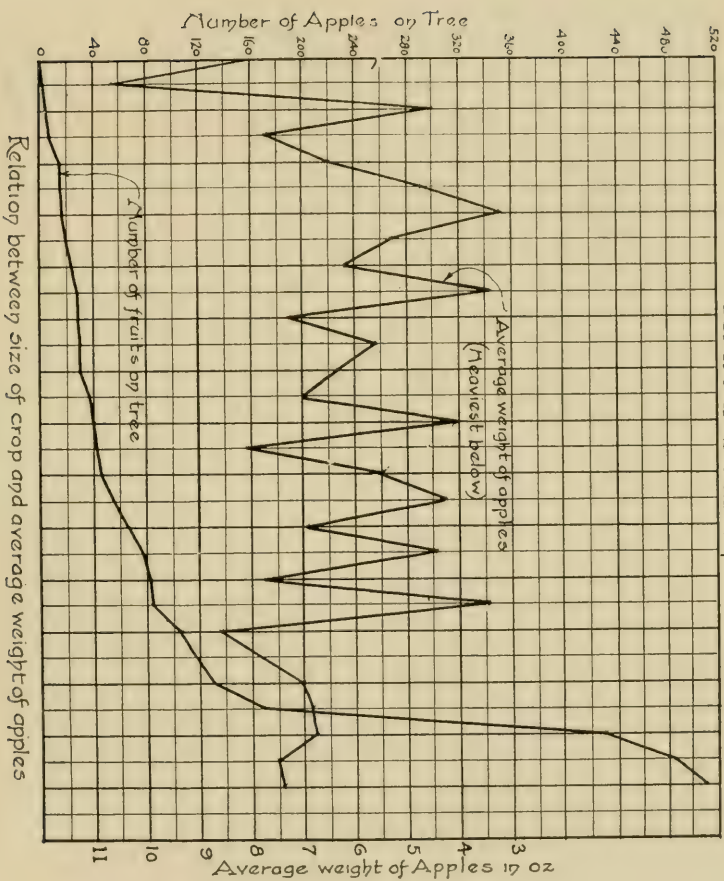
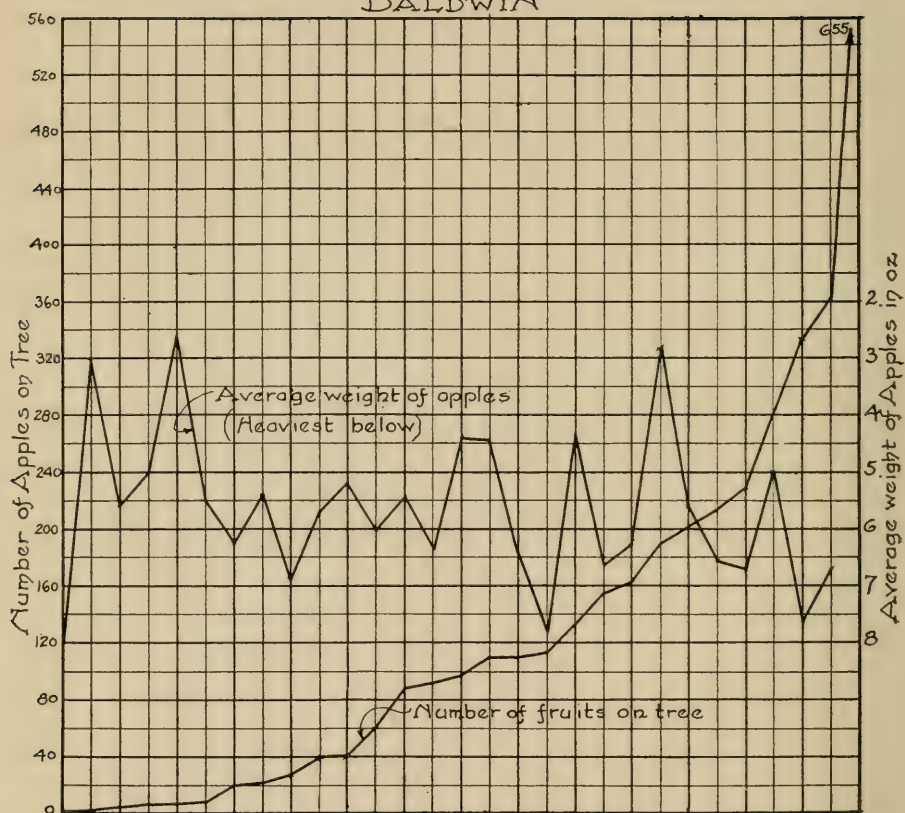


FIG. 22.

BALDWIN



Relation between size of crop and average weight of apples

Fig. 23.

fertilization experiment started at the New Jersey Station in 1896, at which time the trees were planted. This experiment has therefore been running for 15 years, during the last 9 of which some fruit has been borne.

The experiment consists of three plots, each containing two trees of Smith Cider, Baldwin, King, Jonathan, Oldenburg, and Gravenstein.¹ Plot I receives nothing; plot II annually receives 500 pounds per acre of an even mixture of bone, muriate of potash, and acid phosphate; plot III receives the same treatment as plot II, with the addition of 150 pounds per acre of nitrate of soda, the application of the latter apparently having begun in 1904, when bearing had become fairly well started. As an experiment in fertilization, it has apparently not been considered important at the New Jersey Station on account of the small number of trees of each variety, some of which also have died and been replaced.

The experiment is of interest to us, however, especially because of the fact that records of both the number and weight of apples per tree have been kept since the experiment started, with the exception of the year 1910. In that year, the weight of 200 average fruits from each tree was obtained instead.

While not ideal in every way, these data evidently furnish a basis for studying the relation between size of crop and average weight in apples. The objections are chiefly in the youth and varying age of the trees, the latter gradually increasing throughout the period considered, and in the fact that the results were not all obtained in one season, thus introducing differences in rainfall.

The presence of the fertilizer also is a disturbing factor, but the extent of its influence is shown in a table later.

In utilizing the data, we assembled the figures for each variety and calculated the average weights of the apples on each tree during the period covered, from 1902 to 1910.² The relation existing between these average weights and the number of fruits on the tree was then studied by means of curves, the results being shown in Figures 22 to 26.

In preparing the curves shown in the figures above, the average weight of fruits was arranged on the ordinal axis and made to increase downwards, since the relation, if present, would naturally be an inverse one.

The curves show that no definite correlation existed under the New Jersey conditions in any of the first three varieties plotted. In figures 25 and 26, however, some correlation is observable in the latter stages of the curves, i. e., after the number of fruits on the tree has become large,—1200 to 1400 or more,—some inverse relation appears between average size of fruit and size of crop on the tree. This relation would doubtless be clearer, were it not for the disturbing factors mentioned above.

This means in general that if one thins an apple tree of even moderate size before the number of fruits has reached about 1400 or more, he can hardly expect to increase the size of the remaining fruit, and the net effect of the thinning will be an actual reduction

¹The latter variety has yielded so little and so irregularly that it is not considered in our work upon average size.

²The data were obtained from the New Jersey Reports for 1903 to 1908, and from Professor M. A. Blake, by letters covering 1909-10.

in total weight of apples, at least for that year. The exceptions to this may appear in varieties with fruit of unusually large size, or in seasons or locations that are exceptionally dry.

It also means that while the crop-size influence becomes operative and probably dominant after the number of fruits on the tree has passed a more or less definite critical point, yet below this point there is opportunity for other factors to exert their influence. It is here that such factors as fertilizers, cultural methods, moisture supply, and heredity have their opportunity to affect the average size of the fruit. These latter factors also evidently may co-operate in such a way as to raise the critical point somewhat, but in the end the crop size influence, or in other words the amount of moisture available per individual fruit, is always the dominant one.

In this discussion, we have assumed that the variety was properly located in respect to temperature and length of growing season. These factors also are likely to have an influence, as pointed out by Shaw at the Massachusetts Station, to whose work the reader is referred.¹

The effects of pollination and number of seeds per fruit may also be important, as pointed out by Ewert and Müller-Thurgau in Germany, and to their work the reader is also referred.²

Fertilizer Effect on Size of Apples in New Jersey.

As shown by the curves, the size of the crop in these trees was not great enough to materially affect the size of the fruit except in a very few cases. We should therefore expect to find some influence from fertilizers. To determine this we have prepared Table XLVI.

Table XLVI.—INFLUENCE OF FERTILIZERS ON AVERAGE, GENERAL RELATIONS OF LIGHT TO COLOR.

(Calculated from New Jersey Results for 9 years).³

Variety.	I. Nothing.	II. P K.	III. N P K.
Baldwin, ...	6.18 oz.	5.61 oz.	6.12 oz.
Jonathan, ...	3.97	4.18	4.23
Tomkins King, ...	6.47	7.33	7.34
Oldenburg, ...	3.07	3.06	3.12
Smith Cider, ...	3.25	3.62	4.18
Average weight, ...	4.6—	4.76	5.00—
Ratio, Size, ...	100	103.5	108.7
Total yields, ...	5093.7 lb.	10831.8 lb.	8337. lb.
Ratio, yield, ...	100	212.9	163.8
Ratio, yield, .....	.....	130—	100

¹Shaw, J. K. Variation in Apples. Mass. Station Report, 1910, Part 1, pp. 194-213.

²Ewert, R. Parthenocarpie bei der Obstbäume, Landwirtschaftliche Jahrbücher, Berlin, Vol. 38: 767-839, 1909; also Ibid, Vol. 35: 259-287, 1906. Also see article by Müller-Thurgau on "Influence of Seed upon Size, Shape and Color of Grapes." Landw. Jahrb. der Schweiz, Vol. 12: 135-205, 1898.

³This table gives the average of the average weights of fruit for each variety in each year from 1902 to 1910. It is calculated from the data given in the New Jersey Reports for 1903 to 1905, and in letters from M. A. Blake for 1909-10.

OLDENBURG

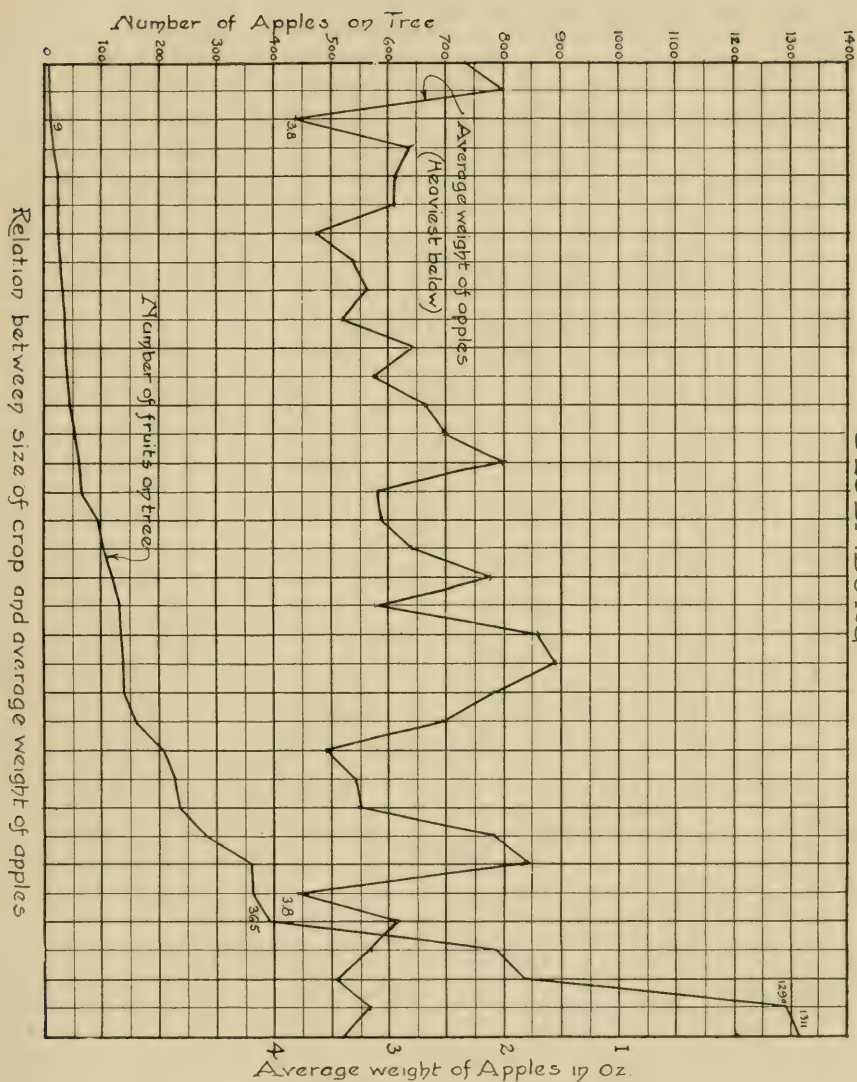
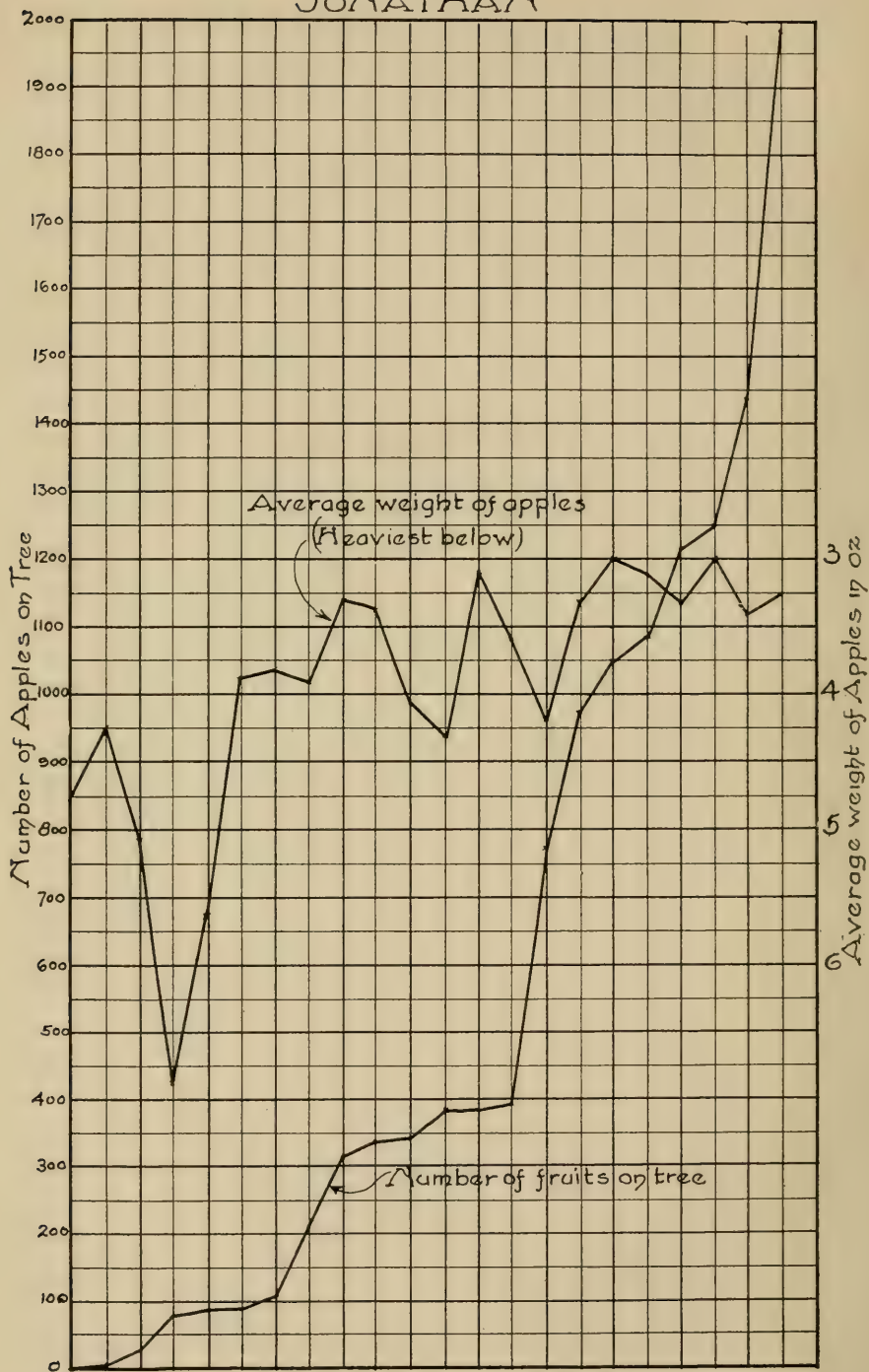


Fig. 24.

JONATHAN



Relation between size of crop and average weight of apples.

Fig. 25.

As stated earlier, the total crop yields here are not strictly comparable because of trees being out or replaced in some of the plots. They are included in the table, however, for the light they throw upon average size. It will be observed that a fairly distinct effect appears on size in both fertilized plots, especially when the increase in crop is also considered. The influence appears to be greater in plot III, where nitrogen has been added to the materials used in plot II.

This may be because nitrogen really increases the size of the fruit, in normally moist seasons. In our own work, however, as shown in Table XXXII, the nitrogen influence has apparently been rather harmful. We suspect therefore, that the increase in plot II of Table XLVI would really be greater than that shown in plot III, if it were not for the depressing influence of the 30 per cent. greater yield in the former case.

FACTORS INFLUENCING COLOR IN APPLES.

In Tables XXX to XXXII, XXXV to XXXVII, an XL together with their following discussions, we have seen something of the detailed effects of various external factors upon color in apples. It remains for us to develop some of the broader phases of this subject, to present some additional data, and to show the relation of the various detailed effects to the main principles governing color in apples.

General Relations of Light to Color.

In apples, so far as the fruit is concerned, there are but two colors to be considered,—yellow and red. Physiologically, the former is connected with colored bodies in the superficial layers of cells. It develops independent of light, and its intensity depends merely upon the degree of maturity or ripeness. The latter, however, is a constituent of the cell sap. It is capable of being influenced by a number of agencies, and its intensity is dependent primarily upon the amount of light that is received during the later stages of maturity.

This relation to light is not true of all red colors in plants. The reds and allied colors of radishes, beets, truffles, potatoes, and carrots develop independent of light.¹ The same is true of the flower colors of tulips, crocuses, and cucumbers. The chlorophyll in algae and in young conifers is also produced independent of light.

On the other hand, the colors of flowers in *Crassula*² and of leaves in *Coleus*,² and most reds that are found in cell sap are apparently developed only with the aid of light. The importance of light, therefore, in the production of red colors in apples is naturally to be expected.

An Experiment on the Relation of Light to Color in Apples.—To determine whether anything else was involved in this development of reds within a given variety, and especially whether these colors could be developed in the presence of light independent of anything that might be contributed by the sap from the tree, in the fall of 1909 we made a test of the effect of light upon apples after they were picked. In this test some 200 York Imperial apples were sep-

¹See Jost's *Plant Physiology*, p. 308.

²See articles by Camille Flammarion in the *Experiment Station Record*, X: 103-114; 203-213.

arated into four lots of equal size, each lot containing approximately the same amount of color at the beginning of the test. Two of these lots were arranged to test the effect of sunlight and two the effect of electric light; one of the lots in each case being darkened and all other factors being kept essentially uniform.

The results of the test in brief were that the lot exposed to sunlight increased in redness by about 35 per cent., while in no other case was any definite increase observable. In some cases an apparent increase in the brightness, though not in the extent, of the redness was observed. But this seemed to be due essentially to the coming up of the yellow colors, thus increasing the contrast.

This test therefore gives us two facts,—first the importance of sunlight, especially in connection with maturity; and second, the fact that color is apparently independent of anything contributed by the cell sap, at least after normal size is reached. To obtain high color, however, it is desirable to maintain connection with the tree as long as possible, because of the unfavorable effects upon keeping quality that result from any considerable exposure of the fruit after picking.

The Dominant Influence on Color in Apples and Its Relation to Known Facts.—Maturity in sunlight on the tree, therefore, is the dominant influence affecting the color¹ of fruit in apples. And, so long as both maturity and light are operating, anything that tends to hasten or increase either will promote color, while factors tending to retard or decrease either will injure it.

The relation of this principle to certain known facts is of interest. Thus we know that manure and nitrogen applications, heavy soils, and excessive cultivation, all tend to decrease color; while light soils, sod or sod-mulch and possibly phosphate and potash applications tend to improve it. These differences are all readily accounted for on the basis of their relation to maturity, though some of them also indirectly affect the amount of light. The first group of factors evidently tends to retard maturity, while the second group hastens it. We also know that dense tree-tops, heavy foliage, and early picking of fruit give us reduced color, while the reverse conditions favor it. These effects are evidently due to modifications in the amount of light, and in one case also the degree of maturity is affected.

Effect of Iron Applications.

The idea that iron in the soil or iron applications have some definite relation to color in apples has long been present in horticulture. We have referred to this before in our discussion of mineral nutrients and we have yet to give the experimental evidence.

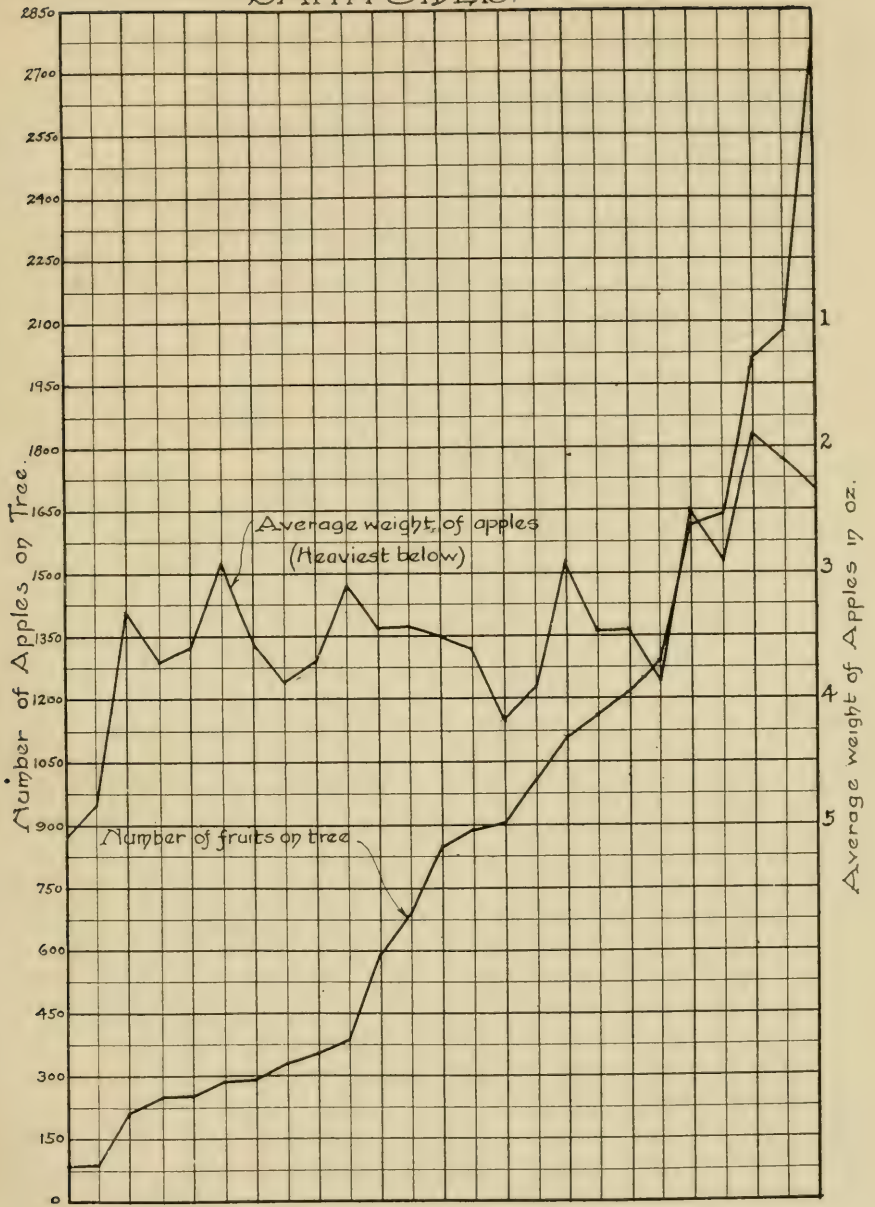
No work with this element has been done as yet in our experiments. It has been applied, however, in the form of iron sulphate, both at the Missouri Station and at Wye College in England. At the former Station, better coloring was reported on both fruit and foliage of trees receiving the applications, but the leaves and peelings contained less iron than those of the checks. The time and amounts of the applications are not reported.²

The work at Wye College was done on trees planted in zinc pots, and the iron sulphate applications were made in connection with complete fertilizers. In their work, the iron had no perceptible

¹"Color" here and elsewhere in this discussion refers to the reds unless otherwise specified.

²Schweitzer, P. Mo. Rpt. 1898: 82-83.

SMITH CIDER.



Relation between size of crop and average weight of apples

Fig. 26.

effect on color. The same was true of potash. In the case of phosphoric acid, however, they reported "highly colored" apples.¹

These results are apparently all that are now available on the experimental use of iron salts upon apples. They are evidently inconclusive, and our present attitude is that as yet the use of iron salts as a fertilizer has not been found to have value in increasing color in apples. This is rather to be expected, since iron is required in relatively small amounts, as indicated above in our composition tables; and it is almost universally present in orchard soils in sufficient amounts.

An Experiment with Fertilizers upon Color of Flowers.

Some work done in Rhode Island, on the effect of certain fertilizers on the color of flowers in a number of herbaceous plants, is of interest in this connection.² This experiment was run for two years, in 1901-02. The effect of nitrate of soda, muriate of potash, and sugar,—all applied at the rate of 1000 pounds per acre,—was tested, the fertilizers being applied in July.

The results were that many of the plants were injured on the plots receiving the nitrate and muriate, and no influence whatever upon color as a result of the different applications could be observed during either season.³

An Effect of Certain Sprays on Color.

Most of the effects upon color indicated above could be fairly readily explained. An effect that we have observed this past season on the relation of certain sprays to color in peaches is less evident in its explanation. This effect we have referred to elsewhere,⁴ and it has also been observed by others. It consisted in an extremely brilliant increase in the red color of peaches on certain plots in which considerable arsenical injury had occurred.

This increase in color was probably due to a not unusual stimulative effect exerted by the arsenical poison, when present in less than killing strengths, coupled with the decreased foliage which admitted more light to the fruit.

We have observed no effect similar to this on apples, though it possibly may be present.

Influence of Variation and Heredity on Color in Apples.

In the discussion above, our attention has been confined chiefly to environmental influences upon color in apples. The influence of internal factors, however, is fairly clear in this connection.

The existence of such factors is obvious in the differences in color between such varieties as Baldwin, McIntosh and Jonathan, on one hand, and Rhode Island Greening, Albemarle and Yellow Transparent on the other. The important question, however, is how have these differences appeared.

¹Gard. Chron. 3 Ser., 29 (1901) No. 752: 332-33.

²Card & Stene. Effect of Fertilizers upon the color of Flowers. R. I. Sta. Rpt. 1903: 213-14.

³Also see article by Blake on "Factors which Determine Color in the Forcing of Roses." Proc. of Soc. for Hort. Science, 1910, pp. 10-23.

⁴Stewart, J. P. The Summer Spraying of Peaches. Pa. State Hort. Assoc. Rpt. 1911: 151-195. Also, Amer. Pomological Soc. Rpt. 1911: 281-292.

Most of them have doubtless come from variations by way of the seed. There is evidence, however, that at least some of them have come from variations in buds or branches from the same tree. This is true of the Banks and the Collamer apples, which have originated from the Gravenstein and Twenty Ounce varieties, respectively, by variations in single branches of their parent trees. In them, the usual narrow red stripes of their parents are broadened so as to much more completely cover the fruit.

In two other cases that have apparently arisen from these same varieties by variations in the buds used in nursery propagation, these stripes are further broadened into practically solid red colors. These are the Hitchings, and the Red Gravenstein from an island in Puget Sound, reported by Beach.¹ The origin of Gano from Ben Davis may be a similar case to the latter.

At least some of these cases also are heritable. This is true of the Banks, which is reported to have been widely propagated in Nova Scotia and to have come satisfactorily true to type in most cases, though not in all. The genuine Gano is well known to be practically constant in its solid red colors, at least within its proper habitat.

These rather striking and apparently heritable differences in color, some of which have certainly originated by vegetative variation, seem more nearly to prove the existence of genuine bud mutations, and the possibility of their utilization in apple improvement along various lines, than any other evidence we have.

SUMMARY AND CONTENTS.

1. In America, the apple is by far the most largely grown fruit. At present also the interest in it is apparently greater than ever before.

2. Production, however, has not kept pace with the increase in planting, some data indicating that the latter recently has been at least three times as rapid as the former. This fact, together with the great expansion in capital involved, emphasizes the necessity for better and more thorough knowledge on the part of all connected with the industry and its development.

3. This publication continues the work presented in our Annual Reports for 1907 to 1910, and in our Station Bulletins 91 and 100. The results now cover four years, and involve 18 experiments and 3,660 trees. Those considered here are chiefly from 2,219 trees, located in ten experiments in as many different parts of the state. They involve ten soil types and 829,527 pounds of fruit. Detailed accounts of these experiments are given, and the results and observations of others also have been introduced where it seemed desirable.

4. The various factors, both internal and environmental, that may influence apple production, are here enumerated, and, a principle or hypothesis is stated, which indicates the general conditions under which any factor may become important. This is a modification and extension of the so-called "law of the minimum," which we have termed the "optimum" principle. See pages 407 to 409.

5. The development of the fundamental facts of orcharding, as well as the development of the best possible practice in any given

¹Beach, S. A. Rural New Yorker 1911: 263.

orchard, calls for extended use of the experimental method. The principal rules and precautions that attend the application of this method to orcharding are stated. Pages 409 to 411.

6. The value of plant-food applications to apple trees has been questioned. In some situations and in the presence of other limiters, this attitude is undoubtedly correct. We find, however, that the annual plant-food draft of a vigorous and productive apple orchard is actually greater for every element than that of a twenty-five bushel crop of wheat. We also find that very important increases in orchard yields may often be obtained with proper applications of plant food. These increases, in some cases in our experiments, have been from four to thirteen times the yields produced on similar adjacent unfertilized plots. The accompanying net gains have been as high as \$267 per acre in a single year. Pages 421 and 465 to 467 and Table XXXIII with context.

7. The ability of trees to maintain themselves over considerable periods without apparent need of extra fertilization is probably not due to their reputed deep-rooting habit nor to other reasons commonly advanced. It seems to be due, however, to their relatively natural demand, their long season of root activity, and the return of most of the plant food of the leaves to the soil. The carbon dioxide and other products developed in the decay of humus and cover crops are also doubtless an important adjunct. See Table XXVII and discussion following, pages 447 to 449.

8. The Mineral Composition of Apples.—(a) A fairly exact knowledge of the composition of all parts of the crop with which one is working is evidently desirable. This we have worked out for the fruit and vegetative parts of apples. For the results and method of obtaining them, see pages 421 to 436, and especially Table XVIII.

(b). In studying the data on composition, some interesting variations appeared, which showed evident migration of mineral elements from the older parts to the younger and from vegetative parts to the fruit. Young twigs and roots, for example, are from 2 to 5 times as rich in minerals as the older wood. Also in crop-years the ash-composition of leaves is much lower than in off years, thus indicating a considerable transfer of materials to the fruit. Pages 432 to 433.

9. The annual weight of wood, leaves, and fruit produced by a mature apple tree is estimated, and the present bases for such estimates are presented. For average conditions in good orchards, these weights appear to be about 100 pounds each of wood and green leaves and 14 bushels of apples per tree. Pages 436 to 439.

10. The Annual Plant-Food Draft of Mature Apple Trees.—Various attempts, both in America and Germany, have been made to answer this question. The essential features of their estimates are presented, and a new approximation, based upon the composition tables and annual weights derived above, has been computed and is presented herewith. See pages 439 to 449, and especially Table XXVI with context.

11. Along with the determination of the amounts of nutrients found in the apple plant, we have brought together the principal facts and ideas now held concerning the special functions and effects

of these nutrients. This knowledge has necessarily been derived from plants in general, hence it has general application to the apple as to any other plant. Such special applications as are evident at the present time, however, have been indicated. Pages 449 to 454.

12. The toxicity of the salts of certain bases, including many of the mineral nutrients, is apparently worthy of much more attention in connection with crop-fertilization than it has received heretofore. Certain anomalous effects of fertilizers upon fruits, observed in our experiments and elsewhere, are explainable on this hypothesis of basic toxicity and its neutralization, and apparently in no other way. Further experiments are in progress more fully to determine the facts. Pages 454-455, and 461 to 465.

13. If the above hypothesis proves finally to be correct, it will make clear the cause and prevention of the apparently new physiologic disease of apple trees, noted by us in our last annual report. It should do this also for similar injuries to fruits that have been observed elsewhere; and by indicating how to eliminate the possible injuries, it should enable us to furnish the most favorable conditions for obtaining maximum effects from fertilizer applications, in apples as well as other crops.

14. The results of *plant-food applications* upon apple production, that have been obtained in our experiments, are given in detail on pages 455 to 467.

(a) These experiments show, in general, that the influence of nitrogen upon yield is likely to be important, whether applied in the form of manure or in commercial forms. Its influence in our total results to date, however, is considerably reduced as compared with earlier returns. This is probably connected with the droughty conditions that have prevailed during the past two seasons, and with the operation of the biennial bearing habit. Present indications are that this reduction in influence is only temporary. See Tables XXVIII to XXXII and context.

(b) The precautions in the use of nitrogen, stated in our earlier publications, have not been modified. These involve the time of application and the relation of nitrogen to color. If applied in soluble form, especially on leachy soils, probably the best time of application is somewhat after petal-fall, when the stored food is exhausted and the need is greatest. Also, on account of its indirect reduction-effect upon color, nitrogen can be used most freely on the earlier soils, or in localities with long growing seasons, or on varieties without red fruit. Nitrogen may be secured in cover crops, manure, or in commercial forms, probably without material difference in effect, if sufficient lime is present.

(c) The influence upon yield of phosphates and potash, when used in connection with other fertilizer materials, is becoming much more distinct and important. Their influence on size, especially that of potash, is also becoming more evident. Their influence when used alone, however, and also their effects on color, are practically nothing as yet. See Tables XXVIII to XXXII and context.

(d) "Floats," when applied alone, continues to show no important beneficial effects. The same is true of lime in the older set of experiments, though rather marked benefits have appeared from it in our later set. An explanation for this is suggested. See Table XXXII and following pages as far as page 465.

(e) Our present observations indicate that there is a relation between certain kinds of fertilization and injury from fire-blight, though the relation has not yet appeared in all experiments. In general, the injury from blight has been greatest on the plots receiving fertilizers that resulted in the most vigorous and succulent growth. This was especially true of stable manure. Page 467..

(f) Our general fertilizer recommendation for bearing apple trees in this state, in amounts per acre, remains as previously stated, viz., 30 pounds of actual nitrogen, 50 to 60 pounds of actual P_2O_5 , and 50 pounds of actual K_2O . This may be supplemented with cover crops, through which all the nitrogen may be obtained, and alternated with stable manure at the rate of about 10 tons per acre, at least every third or fourth year.

15. Results from orchard fertilization in Massachusetts are similar to those obtained by us. They are given in Table XXXIV and context.

16. Attempts to feed trees directly, by means of injections, have thus far proved of little avail. The work on this point has been done elsewhere, and it is summarized on pages 469 and 470.

17. A bibliography of reports and papers bearing upon orchard fertilization and tree injections is given on pages 471 to 474.

18. The influence of various *cultural methods* upon apple production, as indicated by our experiments, is given on pages 475 to 486. In general these experiments show that:

(a) When used without any fertilization, rather marked differences appear between the four cultural methods compared. Tables XXXV to XXXVII and discussion following.

(b) When used in combination with fertilization,—either manure or a complete commercial fertilizer,—these differences are greatly reduced and in some cases reversed. See Table XXXVIII and context.

(c) In the younger orchards, in which the bearing habit is not fully established, the mulch method has thus far proved best in most respects. The apparent influence in hastening bearing noted before has thus been maintained. See pages 476 to 479 and 484 to 486.

(d) In the mature orchard, without fertilization, the tillage-and-covercrop method has thus far proved much superior to mulching. When fertilizers are added, however, the situation is now reversed. This is largely due to a remarkable, consecutive increase in bearing that has occurred on the latter plots. It suggests that proper fertilization may largely take the place of tillage, in some cases at least; and, in the presence of sufficient available plant food, undisturbed root-systems may be more efficient than those annually pruned by current methods of tillage.

19. As previously noted, the lower moisture-draft of legumes, together with their favorable nitrogen relations, makes them especially valuable in orchards as covercrops, intercrops, or permanent covers. We have observed quite marked differences, however, in the moisture draft of different legumes, the more hairy forms being least exhaustive, and hence most valuable as permanent covers. See page 480.

20. The detailed effects of manure in conjunction with different cultural methods are given in Tables XXXIX and XL and their contexts. In general, their addition has been beneficial.

21. A study of the distribution of feeding-roots in apple trees is presented on pages 487 and 488. Under our conditions, the root-feeding zone is relatively shallow. The roots were studied in 28 trees of 10 varieties on 10 different soil types and under two cultural methods. The maximum numbers of feeding roots, on the average, ranged from 2.7 to 12 inches.

22. A bibliography to papers on cultural methods in orchards, and allied subjects, is given on pages 488 to 492.

23. *Variation and heredity* as factors in apple production are discussed on pages 493 to 499.

(a) The utilization of the forces of variation and heredity in the improvement of apples is evidently desirable, though not yet entirely proved to be practicable. If the effort toward improvement is made by way of the seed, an important difficulty appears in the extremely heterozygous condition of the gametes. If the effort is made by way of cion-selection, we find ourselves dealing with "clons," which are essentially identical or at least analogous with "pure lines," and in which the possibility of important progress by means of selection is yet uncertain.

(b) Along the line of cion-selection, however, we have found that important variations do exist between trees of the same variety under similar conditions. Data from experiments elsewhere covering considerable periods show that certain trees have produced from 65.5 to 315.5 per cent. more fruit than adjacent trees under apparently identical conditions. (Tables XLII to XLIV). In our own experiments, twenty comparisons, each involving 10 high yielding versus 10 low yielding trees, show an average difference in yield during three years of over 320 per cent. In other words, 20 groups of trees during three years have produced over 4 1-5 times as much fruit as 20 adjacent groups under apparently identical conditions and treatment. Table XLV and context.

(c) The exact nature and the heritability of these variations are not fully understood. Such evidence as we have at present is rather indicative of non-inheritance, though the case is not entirely settled, and some things point toward final success. Pages 496 to 499, and 505 and 506.

24. A brief bibliography on cion-selection and other phases of apple breeding is given on pages 499-500.

25. Factors influencing *size* in apples are considered in pages 500 to 503, and in Tables XXX to XXXII, XXXV to XXXVII, and XL.

(a) In general, we find that the size of the crop on the tree has no influence on the size of the fruit, until the former passes a certain critical point. From correlation curves, shown in figures 23 to 26, this point is not lower than 1200 to 1500 apples per tree, on trees of only moderate size and age. *Above this critical point, however, crop-size is probably the dominant influence on size of fruit.*

(b) Below the critical point, other factors,—such as moisture-supply, cultural methods, fertilization (especially with manure and potash), temperature and length of growing season, and probably pollination and number of seeds per fruit—all these may exert an important influence on fruit size. When working in conjunction, these latter factors may also materially raise the point at which crop size becomes operative. Pages 501-502.

(c) According to this, if one thins an apple tree of even moderate size before the number of fruits reaches 1400 or more, the size of the remaining fruit will hardly be increased, and hence the net effect of the thinning will be a reduction in total weight of fruit, at least for that year. Exceptions may occur with varieties of extra large size, or in seasons or locations that are exceptionally dry.

26. Factors influencing *color* in apples are considered in pages 503 to 506, and also in the tables indicated in section 25 above.

(a) The yellow colors in apples are independent of light and of nearly all other environmental conditions. The red colors, however, are primarily dependent upon sunlight, and especially upon the amount received during the later stages of maturity. Maturity in sunlight is therefore the dominant environmental influence in the production of color in apples. Hence, anything, that tends to hasten maturity, or to increase the amount of sunlight received, will favor color, while the reverse conditions will injure it. Pages 503 and 504.

(b) Exposure of apples to sunlight after picking increased their redness by 35 per cent., while the checks in the dark and those exposed to electric light showed no definite increase.

(c) Abundance of iron in the soil or iron applications have long been supposed to have some relation to color in apples. The present experimental evidence does not justify this opinion. Pages 504 and 505.

(d) The available evidence upon fertilizers in their relation to color in flowers is also negative, so far as improvement is concerned. Page 505.

(e) Certain arsenical sprays have shown distinct improvements in color, especially on peaches. This is probably due to increased sunlight, following a reduction in the amount of foliage, together with some stimulative effect from mild amounts of the poison. Page 505.

(f) Variation and heredity have important relations to color in apples, and the possibility of their utilization in its improvement is apparently good. Pages 505 and 506.

Respectfully submitted,

July 1, 1911.

JOHN P. STEWART.

PENNSYLVANIA FRUIT SOILS, AND SOIL-VARIETY ADAPTATIONS.

By H. J. WILDER.

CHAPTER I

It is the purpose of this bulletin to discuss: (1) The necessity for careful selection of the soil for orchard purposes; (2) Soil-crop relationship as shown by experimental evidence and field observations; (3) The soils of Pennsylvania with reference to their main or "series" divisions, including brief descriptions of each and their relative productivity; (4) The adaptation of different varieties of apples to particular kinds of soil, and some opportunities for orcharding on Pennsylvania soils as based upon these adaptations, land prices, and accessibility to markets, with reference to the development of both farm and commercial plantings.

THE NEED FOR SOIL SELECTION.

The selection of the soil for orchard planting has received relatively little attention in the past as compared with that given to selecting soils for other special crops. In the production of the latter, such as tobacco, onions, garden and floral crops, competition has forced the selection of favorable soils as well as suitable conditions. The most successful growers have learned through experience, moreover, to discriminate carefully in choosing their soils.

The general farmer has not advanced so far in the matter of selecting particular soils for his crops, or stated conversely, in using his soils to grow only those crops which they are best adapted to produce. This is largely due to the fact that the money returns per acre are much less than from special crops and, hence, it has not been so essential to select soils with as much care as for special crops. Even so, in the eastern United States there are many soil areas from which general farming has been driven because the soils were not adapted to such use. And this statement is not meant to include rough lands which have been unable to compete on account of the relatively heavy expense of working them.

There is no longer any question as to whether orcharding is a specialized business. The steadily increasing demand for orchard products of select appearance has compelled growers, who would succeed, to spray thoroughly, to maintain a well balanced wood growth, and to market the fruit in an attractive manner.

As a result of the vast amount of orchard experience already acquired, it is apparent that some soils have given better returns than others. Hence, we get from many sources the prescription of "a deep well drained soil for successful apple growing." No one will question the excellence of this general rule, which is in fact just as applicable to other crops as to apples. But there is a tremendous

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